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ALUMINUM PAINT AND POWDER

BY
JUNIUS DAVID EDWARDS

ASSISTANT DIRECTOR OF RESEARCH
ALUMINUM COMPANY OF AMERICA

Second Edition
Revised and Enlarged

FIRST EDITION WAS TITLED:
ALUMINUM BRONZE POWDER
AND
ALUMINUM PAINT

شعبہ کیمیا - جامعہ عثمانیہ
حیدرآباد دکن

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Preface

The year 1936 marks the fiftieth anniversary of the invention, by Charles Martin Hall, of the process in commercial use today for the production of aluminum. By this process aluminum was promoted from the laboratory to the rank of a work-a-day metal. Although aluminum bronze powder has been commercially available for most of this period, the extent of its usefulness had not been realized until recent years. Research and development, quickened in pace by the World War, created the fundamental background of knowledge and experience on which is based the present extensive use of aluminum powder. This development has been crowded into less than one-third of the commercial life of the metal. Progress has been correspondingly rapid and it is little wonder that the first edition of this book, although published only nine years ago, should be inadequate for the paint technologist of today. The new edition is, in fact, a new book; and even though it is more than double the length of the first edition, many subjects of interest have had to be briefly discussed, or in some cases, omitted for lack of space.

A substantial share of the technical information presented in this book results from the work of the author's associates in the Aluminum Company of America, and to them much credit is due for placing aluminum powder in the ranks of the commercially important paint pigments. To Robert I. Wray, Chief of the Paints and Finishes Division, Aluminum Research Laboratories, the author is particularly indebted for his constant help and advice, based on twelve years of research and investigation in the technology of aluminum paint.

Research in all lines of paint technology has made great advances in the last ten years and many investigations in other fields have been of practical value in the formulation, application and testing of aluminum paint. It is sincerely hoped that aluminum powder is doing its share in adding to our fundamental knowledge of paints and finishes and increasing their usefulness.

JUNIUS DAVID EDWARDS.

New Kensington,
Pennsylvania.
May 1, 1936.

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Chapter 1.

Manufacture of Aluminum Powder

The bronze powder art was originally an offshoot of the goldbeater's art. The goldbeater learned to hammer sheets almost unbelievably thin,—only a few millionths of an inch in thickness. This was accomplished by interleaving sheets of gold foil with goldbeaters' skin and beating the pack with a heavy hammer until the requisite thickness of gold leaf was produced. This gold leaf could then be cut or shredded into minute pieces so as to make a flake-like powder,—the scraps served excellently for the purpose. The shredding was done by rubbing the gold leaf through a fine mesh wire sieve. Naturally, such a powder was very expensive and the production necessarily limited. However, the metallurgist in time developed base metal alloys that duplicated the color of gold very satisfactorily; in fact, the metallurgist supplied alloys that could be given almost every tint of the rainbow. Human ingenuity then devised mechanical means to replace the tedious manual methods of the goldbeater, and the modern bronze powder art was born about the middle of the nineteenth century.

The story is told that Sir Henry Bessemer was so impressed with the potential profit in the sale at about twenty-five dollars per pound of gold bronze powder made from brass that he devoted himself to the problem of its manufacture.⁵ The obvious method of attack was to substitute mechanical means for the laborious handwork of the goldbeater. It was not so difficult to reduce metal to fine particles, but to give them the form, color and luster of the bronze powders on the market was a problem for which he did not readily find the solution. However, after several years' experimentation he was successful. By keeping his process secret, he dominated the market for many years to his own substantial profit. His methods were the forerunners of the processes in use today.

The name bronze powder undoubtedly came from the copper alloys first used in the production of these metallic powders. By alloying and by heat treating, bronze powders of wonderful beauty and color were produced, but silver and tin were about the only available metals which would give a "silver bronze powder." Silver was expensive and tin did not adapt itself readily to current manufacturing methods.

By the end of the nineteenth century aluminum had become commercially available for the production of metallic powders of silvery hue. Little has been published regarding the early history of the manufacture

of aluminum bronze powder. A search of the files of The Aluminum World⁶ discloses the fact, however, that aluminum powder was being advertised for sale by W. H. Kemp Company in 1894. This powder was manufactured abroad and imported; the old inventory records of the Kemp Company show importations as early as November, 1892.

Although not made from a bronze alloy, nevertheless custom dubbed this new pigment "aluminum bronze powder." The name is sometimes misleading to metallurgists not familiar with the bronze powder art, since they have given the name "aluminum bronze" to a copper-aluminum alloy (10 per cent aluminum) of beautiful golden color. As a matter of fact, the alloy aluminum bronze is sometimes used for the manufacture of a very high grade gold bronze powder. However, when some distinction must be made between a lustrous, flake-like powder and the utterly different, dull, and sometimes gray to black aluminum powders made by various atomizing and pulverizing methods, the name aluminum bronze powder is useful. Recently, however, the more common practice has been to omit "bronze" from the name and simply call it "aluminum powder." In this book the two names will be used interchangeably, following the usage now prevailing. Although aluminum powder is the newest of the metallic bronze powders, it has proved so useful that it has now become the most important of the group.

Manufacture of Aluminum Powder.

There seems to be but one fundamental way to make metallic bronze powders, no matter what the specific mechanical arrangement employed. By pressure, the metal must be forced to "flow" into flake-like particles. Pressure, such as in stamping, produces a burnishing action and enhances and conserves metallic luster and brilliancy. Abrasion and grinding produce a reduction in size of particle, but the powder so produced is dark in color and granular in nature. It is almost totally lacking in the brilliant flakes which give bronze powders their characteristic appearance and value. Abrasion and grinding action must therefore be reduced to a minimum.

As usually carried out, the manufacture of aluminum bronze powder resolves itself into a process of hammering aluminum under mechanical stamps until the particles are small enough and thin enough for the desired purpose. As a raw material, aluminum of a fairly pure grade is desirable. The best grades of powder are made from aluminum running 99 per cent or better in purity. If iron and silicon are present in excessive amounts, they render the metal hard and difficult to stamp into thin flakes. Furthermore, they form constituents in the aluminum which are blue to gray in color, and tend to detract from the natural silvery hue of the aluminum.

Since sheet aluminum is well on the way to foil and flake, it provides—when available—a convenient material with which to start the stamping operation. It is cut into small and uniform pieces and reduced to as

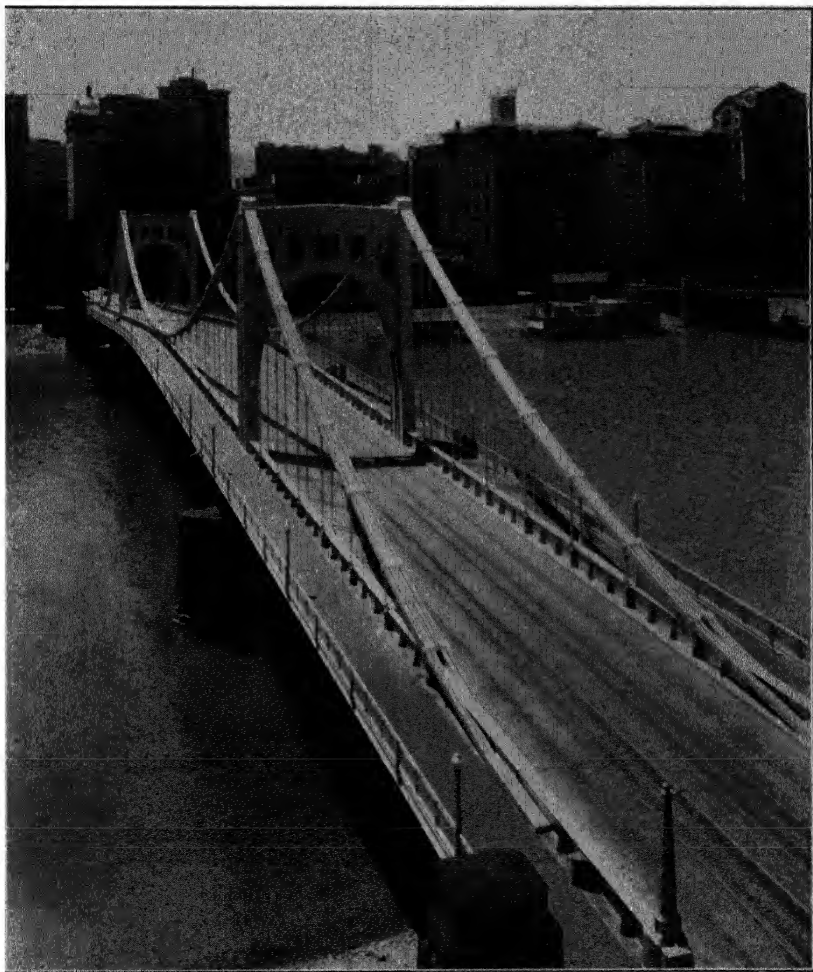


FIGURE 1. The Seventh Street Bridge, Pittsburgh, Pa.; one of three "sister" bridges, the design of which won the 1928 Annual Award of Merit given by the American Institute of Steel Construction. Aluminum paint has served to emphasize the graceful and pleasing construction of these three bridges.

uniformly soft and ductile condition as possible by annealing. The element of uniformity is important, for if hard aluminum alloy sheet is mixed in with pure aluminum, the production of a satisfactory powder is rendered difficult if not impractical. Foil scrap, being thin and bright, also provides a suitable material for the production of aluminum powder. Where thin sheet is not available, the equivalent is sometimes made by pouring molten aluminum onto a revolving plate where it solidifies in a thin film which is continuously removed with a scraper. It is essential that the aluminum be free from oil, grease, dirt, pieces of iron, and other substances which will give a powder which is gray in color and of inferior quality. For this reason scrap aluminum can only be used if it is strictly clean and free from such contamination.

Stamping Operation.

The stamps are of various design, according to the particular ideas of the maker and user. In general, though, they consist of a series of steel hammers raised by cam action and allowed to fall on a steel anvil or mortar, which is suitably enclosed. These stamps are customarily arranged and operated in banks. The small pieces of aluminum sheet are first placed under heavy duty stamps, where the reduction to flake begins. The product of the heavy stamps consists of large, irregular-shaped flakes, commonly called shrode, and the heavy stamps are known as shredders. In order to keep the pieces of aluminum from welding together, a very small amount of lubricant is used to coat the metal pieces during the stamping operation. The use of a suitable lubricant is also said to facilitate the breaking up of the large flakes into smaller flakes as the stamping proceeds. Various lubricants have been employed, such as tallow, stearic acid, olive oil, rape oil, etc.; mineral oils are unsatisfactory for this purpose. As the stamping proceeds, the continual cold working not only beats out the aluminum into foil-like sheets, but also hardens and embrittles the metal so that it readily breaks up into smaller and smaller flakes. The stamping of flake against flake also assists in shearing the larger flakes into smaller ones. At a suitable point the flake-like material is transferred to lighter stamps better adapted to hammer it out into the thin particles which are to constitute the final product. After being transferred from the shredder, the stamping operation is finished in either 1 or 2 additional stamps of lighter weight. The powder is then sifted and the "tailings" or over-size particles are returned for further stamping. The total time of stamping will obviously depend upon the size of the original pieces of aluminum, and the force and number of blows delivered by the stamps. It usually takes from 5 to 10 hours and is a time-consuming operation, requiring skillful attention for its proper execution. In fact, the production of a powder meeting today's requirements is an art which calls for the most careful selection and control of all operating details. The stamping operation can be made continuous, by continuously removing the fines from the

stamps by means of an air lift. Air drawn through the mill at controlled speed will pick up the fines as they are produced and discharge them into a collecting system.

The product of the stamps is made to conform to established grades by sifting operations. Wire sieves and silk bolting cloth are commonly employed in the sifting operation, although air separation is suitable for the handling of the finer particles. The appearance of the powder is largely influenced by the relative proportions of large and small flakes.

Polishing.

Most grades of aluminum powder are submitted to a final operation known as polishing. The conventional type of apparatus for polishing is a cylindrical drum with a series of brushes bearing lightly against the inner surface. The powder is placed in the drum with a small addition of lubricant, and the brushes and cylinder, or either, are revolved. The polishing smooths out the flakes by causing them to rub against each other and against the cylinder and brushes. During the process, each flake is also coated with an extremely thin film of lubricant, which confers upon the flakes the power of leafing, a property which will be discussed later. The frictional heat developed by the revolving brushes serves to soften the polishing agent and permit its uniform distribution in an exceedingly thin film on each flake. Stearic acid is the usual lubricant employed at this stage, although manufacturers, by experiment have developed a variety of useful compositions for this purpose.

When the polishing operation is complete, the powder is ready for packing. During the first few weeks thereafter, some change appears to take place between the metal flake and the film of lubricant, which tends to arrange and "fix" the film upon the flake; this aging materially improves the appearance and quality of the powder. The leafing power of the powder develops during this period. The powder is then ready for use.

The manufacture of aluminum bronze powder, as well as other types of bronze powder, has been described in detail by Oliver Smalley in a series of articles in *The Metal Industry*.⁵ Otto Von Schlenck⁷ has also published a discussion of bronze powder in *Metal Industry* (New York). For a description of the machines employed and further details of their operation, the reader may consult these articles.

Hall Process.

E. J. Hall² discovered that the stamping process could be carried out efficiently in a ball mill under certain conditions. With the aluminum in comminuted form, he charges into the ball mill an inert liquid such as mineral spirits and a lubricant in such proportions as to form a sludge of creamy consistency. The sludge uniformly coats the balls in the mill, and when the mill rotates, the aluminum is hammered into flakes under the countless impacts of the polished steel balls. The liquid is

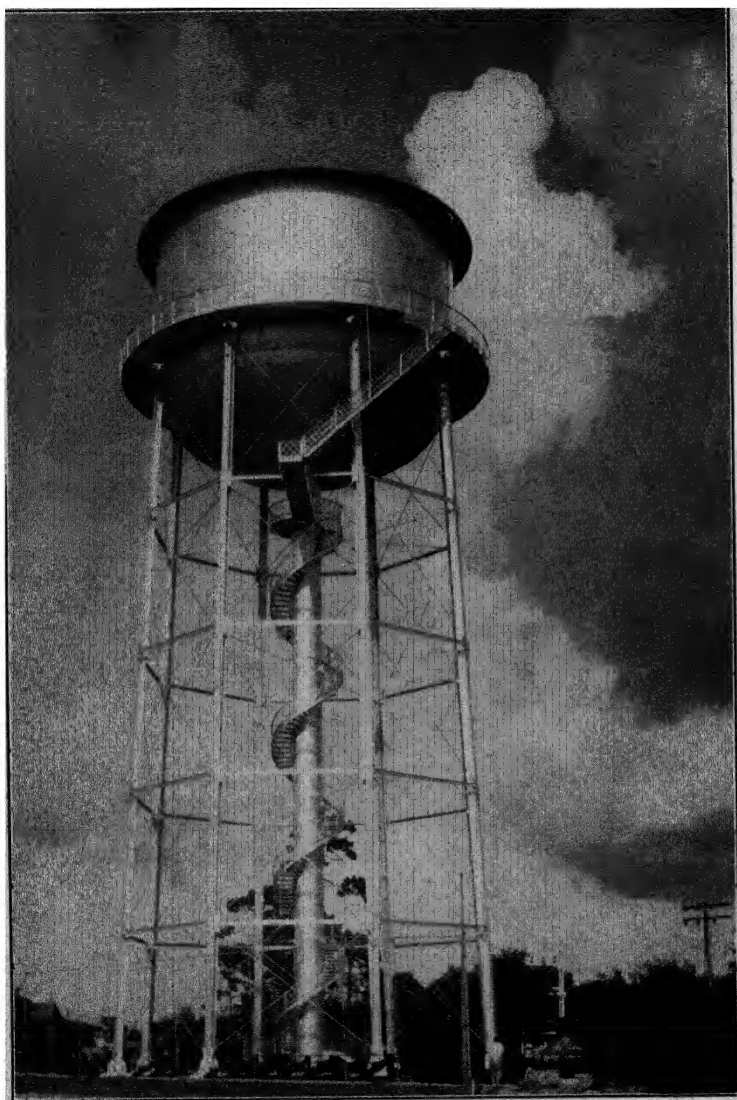


FIGURE 2. Municipal water tank at St. Petersburg, Florida, protected with aluminum paint.

chosen of high enough boiling point so that volatilization losses will not be excessive during the flaking operation, but yet it can be removed afterwards. When the ball mill operation is finished, the liquid is evaporated and the powder is recovered in the dry state.

Hametag Process.

The Hametag process⁴ of making aluminum powder also employs a ball mill, but the operation is carried out dry and in the presence of an inert gas. The following outline of the process is taken from a detailed description by Dumas.¹

The aluminum in granulated form or as small scraps of foil having a thickness of .006 to .040 mm. is fed into one end of the ball mill through a closed hopper. A lubricant is also added to keep the flakes from welding together. A current of inert gas circulates through the mill and carries the flakes suspended in the gas stream into a separator where the over-size flakes are removed and returned to the mill. The fine flakes are removed in a cyclone separator and the gas re-circulated through the ball mill.

The fine flakes of aluminum are automatically transferred to the polisher. This is a cylinder in which rotating brushes, pressing against the wall, spread a thin film of polishing agent on the flakes. The powder passes through the polisher continuously and is discharged into cans at the other end of the polisher, as a finished product. The inert gas which circulates through the equipment is made by surface combustion of illuminating gas; the moisture in the gas is removed by passage through quick-lime.

Hall Paste Process.

Hall is also responsible for the introduction of aluminum pigment in a new form—aluminum paste. Aluminum in comminuted form, mixed with mineral spirits and a lubricating and a leafing agent, is stamped to fine flakes in a ball mill.³ Under the conditions of operation, a film of leafing agent becomes adsorbed or attached to the flakes in such a way that they leaf readily in an oil or varnish vehicle. After removing excess liquid to adjust the metal content to about 60 to 70 per cent, the product is a homogeneous stable paste, suitable for use in paint. A very finely flaked product is made in this way and its use is being rapidly extended as its characteristics become better known and appreciated. Where tests on aluminum paste or products made with it are discussed in this book, it is the aluminum paste made by the Hall process which is referred to.

Powdered or Atomized Aluminum.

Another form of finely divided aluminum is known as atomized aluminum, or sometimes just powdered aluminum. It is made by disintegrating a stream of molten metal with a blast of steam or air. The

molten metal is blown into very fine particles more or less spherical in shape; the product is usually dark gray in color with much the same appearance as zinc dust.

It has sometimes been supplied on orders which called for "aluminum powder," and which did not make it clear that aluminum bronze powder was required. Atomized aluminum is not a suitable material for the production of aluminum paint. It may, however, be used as a starting material in the production of paste.

Grained Aluminum.

If molten aluminum is stirred slowly while it is solidifying, it breaks up into fine grains because it is "hot short" at temperatures not too far below the melting point.⁷ The product made in this way is known as "grained" aluminum. The particles are rough, irregular-shaped grains which vary in size from about $\frac{1}{8}$ inch to grains about $\frac{1}{8}$ to $\frac{1}{4}$ inch in width or length. This material would not be mistaken for atomized aluminum or aluminum bronze powder. One of its important uses is in the Thermit reaction.

Granulated Aluminum.

Granulated aluminum is made by pouring molten aluminum through a vibrating iron sieve and allowing the particles of molten metal to fall into water. The particles formed in this way are flattened drops of aluminum and vary in size up to about $\frac{1}{2}$ inch in diameter. It is used almost exclusively in the deoxidation of steel.

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- ³ Hall, E. J., U. S. Patent 2,002,891, May 28, 1935.
- ⁴ Kramer, Erwin, U. S. Patents 1,832,868, Nov. 24, 1931; 1,930,684, Oct. 17, 1933; 1,932,741, Oct. 31, 1933.
- ⁵ Smalley, Oliver, "The Manufacture of High Grade Aluminum and Bronze Powders"; *Metal Ind.* (London), 24, pp. 273, 296, 445, 493, 569, (1924); 25, pp. 169, 369 (1924); 27, pp. 1, 93, 185, 283, 575, (1925).
- ⁶ *Aluminum World*, 1, p. 58, (1894).
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Chapter 2.

Some Properties of Aluminum Powder

Microscopic Appearance.

The flake-like character of aluminum powder is quite apparent upon close visual examination. It is especially well shown, however, by examination under the microscope. Fig. 3 is a photomicrograph of several flakes of aluminum powder taken at a magnification of 500 diameters with reflected light. The somewhat irregular shape of the flakes is only what would be expected from the nature of the stamping process. In the photomicrograph the flakes appear lined with irregular dark markings. These are fine "wrinkles" and indentations in the sur-

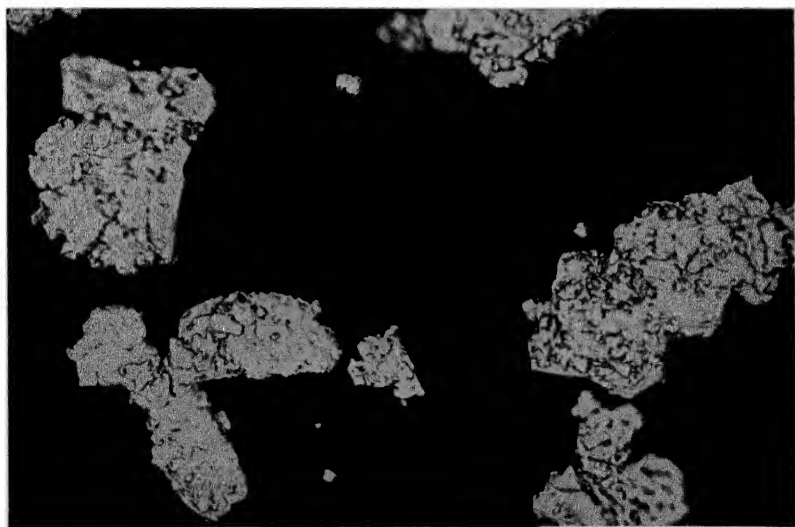


FIGURE 3. Aluminum powder magnified 500 diameters; photographed with reflected light.

face of the flake, which result from having been stamped in contact with many other flakes; under the vertical illumination of the microscope they reflect no light through the eye-piece and hence appear as dark lines. This wrinkled surface is no disadvantage, however, since it can only add a slight diffusing effect to light reflected from it. In general, the

polished flakes are reasonably flat, as can be judged from the fairly good focus obtained over the whole surface.

Figure 4 shows a photomicrograph of powder taken by transmitted light at a magnification of 100 diameters. The flakes appear in silhouette and their characteristic shape is very apparent.

Thickness of Flake.

The thickness of flake is a matter of practical interest; it is also a difficult value to determine accurately. The individual flakes obviously exist in a wide range of widths or diameters, and considerable variation may be expected in the thickness of flake. An estimate of the average

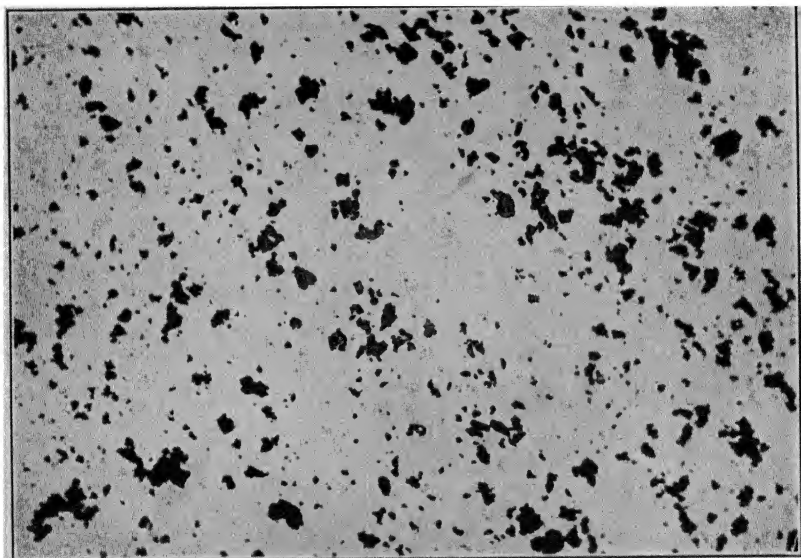


FIGURE 4. Aluminum powder magnified 100 diameters; photographed with transmitted light.

thickness of various powders has been made in the following way: A small, weighed amount of powder is carefully dusted onto the surface of clean water which completely fills a shallow rectangular pan. The powder, not being wet by the water, remains on the surface and spreads out to a mirror-like film if the operation has been skillfully done. The surface is not completely covered, but if a strip of paraffin-coated glass is started at one end and moved along the surface while resting on the sides of the pan, it compresses the film into rectangular shape and largely fills up the voids. The area occupied by the powder is reduced until the film just begins to wrinkle; at this point, if conditions are ideal, the flakes are all lying flat on the surface and touching each other. Knowing the density of the powder, its volume and area,

the thickness can be calculated. A series of measurements on various grades of powder gave values ranging from 0.00007 inch to 0.00001 inch. The average flake thickness of a very fine grade of domestic powder was found to be 0.000012 inch. The flakes in some of the aluminum pastes made by the Hall process are substantially thinner than 0.00001 inch. This method of measurement has been developed into a quantitative procedure and is described in detail on page 36 under the heading, "Covering Area on Water."³

Ritter⁵ has measured the thickness of flake in a fine powder by placing the flakes between plane glass plates and counting the interference lines with sodium light. The finest powder examined was said to have an average flake thickness of 0.000023 inch, with limits of 0.000047 to 0.000012 inch. Von Schlenck⁸ gives the figures 0.00001 inch to 0.00002 inch for the thickness of flake, without any information

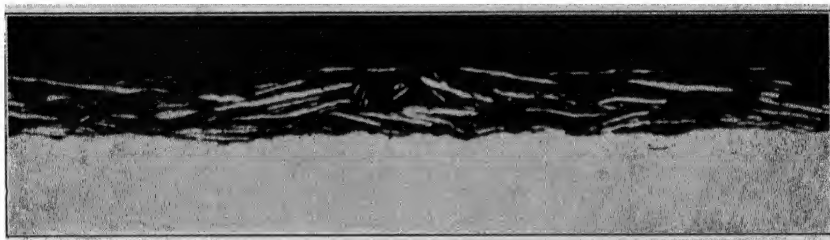


FIGURE 5. Cross-section of a one-coat aluminum paint film (magnified 500 diameters); leafed area appears as thin line at the surface of the paint film; white area below is aluminum sheet to which the paint was applied.

as to the method of measurement. These figures are of the same order of magnitude as those determined by the "covering area on water" method. A good idea of the ratio of diameter of flake to thickness can be obtained by examination of the flakes shown in the cross-section of a paint film in Fig. 5. It should be borne in mind that the actual dimensions of the flakes are only one five-hundredth of those in the photomicrograph. Aluminum paste (covering area about 12,500 sq. cms. per gram of aluminum) was used in the proportion of 2 pounds of paste (65 per cent aluminum) per gallon of vehicle in making the paint for this film.

By counting the number of flakes in a measured area of the magnified cross-section, and knowing the per cent by volume of aluminum in the dried film, a rough estimate of the number of flakes of aluminum in a gram of powder of this fineness can be arrived at. The number of flakes in a gram of powder can also be calculated from the average dimensions and the density of the flakes. The two methods give values of the same order of magnitude,—namely, 10 billion to 20 billion flakes per gram of aluminum powder.

The practical point is that, with flakes of a given area, the thinner they are, the greater the number of flakes per unit weight. A film of aluminum (density 2.5 grams per cc.) weighing 1 gram and having a thickness of 0.00002 inch (.0000508 cm.) would cover an area of 1220 square inches (7870 square centimeters).

Density.

The density of pure aluminum is very close to 2.70 grams per cc. Aluminum powder has, however, a substantially lower density because of the lubricant and oxide film on each particle. Three duplicate determinations gave an average value of 2.54 grams per cc. for the real density of the Standard Varnish grade of aluminum powder. A finer grade of powder showed a density of 2.55, and a coarser grade a density of 2.59 grams per cc. A satisfactory average value for the density of aluminum powder would be about 2.55 grams per cc. Aluminum powder is so "fluffy" that the *apparent* density is substantially lower; it depends to a large extent, of course, on the amount of settling or packing which the powder has undergone. If powder is scooped up with a minimum of settling or tapping, the apparent density may be as low as 0.7 or even lower. The higher the covering area of a powder, the bulkier it is and the lower its apparent density.

An aluminum paste of 65 per cent metal content was found to have a density of 1.47.

Grades of Powder.

The system of grading and classification of powders varies according to the individual manufacturer. The practice of Aluminum Company of America is to designate powders for use in paint and lacquer as "varnish" powders; for example, "Standard Varnish." The various grades are further distinguished by their characteristic distribution of particle sizes; they are known as Extra Brilliant Varnish, Standard Varnish, and Extra Fine Varnish.

The largest flakes in Extra Brilliant powder are larger than the largest ones in Standard Varnish powder. Similarly, the largest flakes in Standard Varnish powder are larger than those in the Extra Fine grade. The average or characteristic particle size, therefore, appears to decrease in the same order. Each of these grades of powder is made independently. A given charge is stamped until a suitable proportion of fine particles has been produced and separated from the over-size particles. In this way a substantial proportion of the particles of extreme fineness are included in each of these grades. The Extra Brilliant powder has more and larger coarse flakes than the Extra Fine grade, but the Extra Fine grade has more of the extremely fine particles. Even the Extra Brilliant grade, however, has a substantial proportion of the extremely fine flakes passing through a 325-mesh screen.

A screen analysis of Standard Varnish powder, for example, might show a distribution of particle size somewhat as shown in Table 1. In this powder a substantial portion of the flakes passing through the 325-mesh screen are so fine as to pass through a 400-mesh screen.

TABLE 1.
SCREEN ANALYSIS OF TYPICAL ALUMINUM POWDER.

Mesh Size	Per cent
On 150-mesh	0.6
Thru 150-mesh and on 200-mesh.....	12.8
Thru 200-mesh and on 325-mesh.....	32.0
Thru 325-mesh	54.6

The present division of grades of bronze powder with regard to maximum mesh size is—through 120 mesh for the Extra Brilliant grade, through 140 mesh for the Standard grade, and through 160 mesh for the Extra Fine grade. The Standard Lining grade of powder is classified as through 200 mesh, and the Extra Fine Lining grade as through a 325 mesh screen. However, when any of these grades of powder are tested on standard sieves, they will show a small residue on a sieve corresponding to their maximum mesh size for reasons explained on page 33.

To a great extent the appearance of a powder is modified by the size of the largest particles present, even though they are present in relatively small proportion. The larger particles have, obviously, a large reflecting area and give a marked brilliance to the powder. The small particles are essential, however, in giving continuity to the leafed surface and durability to the paint film.

It is difficult to judge the value of a powder from visual examination alone, and it is usually necessary to have complete data on particle-size distribution and leafing power before a sound opinion can be expressed. For example, a powder, because of the presence of an appreciable proportion of the larger particles, in bulk may appear brighter than another powder of similar grade. However, the second powder may carry a much larger proportion of the extremely fine particles which are most effective in leafing, and when applied in the form of a paint, give a brighter film than the first. Because of the different standards set by different manufacturers, these factors should be taken into account when comparing powders in which the relative particle-size distribution is characteristically different.

A series of powders is made for use in printing inks, sign painting, decorating and similar purposes. These are finer than the Varnish powders and are called Lining powders; their names are Standard Lining and Extra Fine Lining.

In addition to the Varnish and Lining powders, another group is known as "Litho" powders. The Litho powders are used for printing and decorating processes in which the powder is dusted on and adheres to the inked impression. The excess powder is blown or brushed off, and it is essential that it be readily removed without staining the surface. Litho powders are therefore polished with a minimum of polishing medium. Extra Brilliant Litho, Standard Litho and Extra Fine Litho are the regular grades, with particle sizes closely corresponding to the varnish powders previously mentioned. A special grade of Litho powder is extensively used in the coating of paper as described in Chapter 8.

Unpolished powder is also used for special purposes. Another special grade, known as "Flutter," is very coarse (through 18 mesh), and is used largely for decorative applications and fireworks.

Grades of Paste.

Because of differences in the methods of manufacture, aluminum pastes are not classified on quite the same basis as are the dry powders. As a rule, they are of very fine mesh size and are comparable with the Lining grades of powder. Standard Paste will show about 98 per cent of the flakes passing through a 325-mesh screen when tested by the wet screening method (see p. 34). A finer paste—Extra Fine Lining Paste—shows only a trace of metal remaining on a 325-mesh screen. The pigments in these pastes are further distinguished by increasingly high covering areas (see p. 40). For special applications the character of the liquid in the paste may be changed to make it compatible with certain vehicles.

Leafing.

One of the most useful and characteristic properties of aluminum powder is its ability to leaf in certain liquids. The powder, when stirred in a vehicle like oil or varnish, for example, swirls around and part of the particles come into the surface layer, where they remain to form a practically continuous metallic film. The aluminum flakes are specifically heavier than liquid, yet the effect of particle shape and the surface tension forces between flake and liquid are sufficiently great to hold them at the surface in spite of the difference in density. The term "Leafing" is very descriptive of the phenomenon, since the flakes in the film are arranged much like fallen leaves.

The formation of a leafed film of aluminum powder can be readily followed in detail under the microscope and is a very interesting phenomenon. After considerable experimentation, Mr. Louis Isaacs, of the Motion Picture Producing Company, succeeded in recording a moving picture of the process. Aluminum powder suspended in a black vehicle to give photographic contrast, was placed on a microscope slide and photographed at a magnification of about 10 diameters. Because of the magnification employed, the short exposure, and the very small

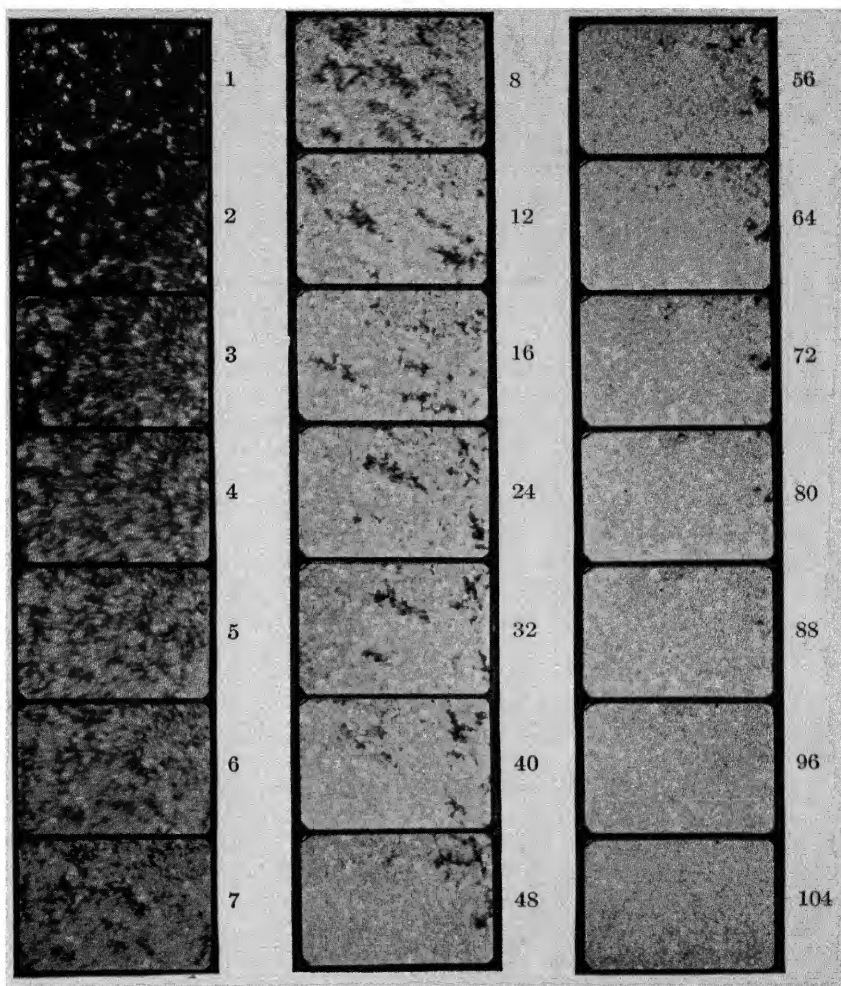


FIGURE 6. Motion picture of process of leafing of aluminum powder in an aluminum paint film; the number beside each frame indicates its order number in the original negative as explained in the text.

distance from paint film to lens, the illumination problem was a difficult one. Part of the film is reproduced as Figure 6. The first frame shows the paint immediately after stirring had been discontinued. The first eight frames represent the first half-second, since the exposures were made at the rate of sixteen per second. The rapid motion of the particles at the start is shown by the slightly blurred and elongated shape of many of the flakes. The powder leafed very rapidly in this mixture and the leafing was about 90 per cent complete in one second. The next frames shown are the 12th and 16th; from this point on, only every eighth successive frame is reproduced, and each frame represents an additional time interval of 0.5 second. The last few small holes in the paint film filled up slowly but surely, so that after about six seconds leafing was complete.

The ability to leaf is determined by the properties of both the powder and the liquid. Unpolished powder, practically speaking, will not leaf in oil or varnish. The film of polishing agent placed on each particle during the polishing process is what confers this property. A rough estimate shows that this film may vary in thickness from a layer a few molecules deep to a layer 30 or 40 molecules deep, depending upon the amount of polishing medium used. It seems probable that the molecules in the outer surface layer are specially oriented and that this orientation is important in determining certain of the leafing characteristics. The orientation of this surface film is one of the changes going on during the so-called aging of the powder after polishing. Naturally, the kind of polishing medium employed, as well as a variety of other factors, influences the final results; some of these will be discussed later.

Some vehicles and volatile thinners promote ready leafing, while others are poor or indifferent in their action. There is a significant relation between the "leafing power" and surface tension of liquids. Other factors being equal, leafing seems to increase with increase of surface tension of the vehicle. The leafing power of a powder may also deteriorate or entirely vanish as the result of long-continued contact with a liquid or a paint vehicle. This fact presents quite a problem in the manufacture of ready-mixed aluminum paints.

The formation of the leafed film can be readily observed, even with the unaided eye. The distribution of the remaining powder beneath the leafed film is not so readily ascertained. In Fig. 5 is shown a cross-section of an aluminum paint film photographed by reflected light; the aluminum flakes appear white by reflection. The leafed film appears as a thin line at the surface of the paint coating. The remaining flakes appear to be more or less uniformly distributed between the painted surface and the leafed film. The concentration of powder in the film, the viscosity of the vehicle, and the conditions of application would have an important effect upon the resultant distribution in any particular case. It is obvious, however, that these thin, flat flakes dispose themselves to give a relatively impermeable film of high opacity.

Handling Aluminum Powder.

In handling and using aluminum powder, it must not be forgotten that it is a combustible dust in the same sense as starch, flour, powdered coal, etc. It is not, however, an explosive. A pile of aluminum powder is rather difficult to ignite and once started will burn quietly without smoke or flame in contact with air or a source of oxygen. Not being itself explosive, it is entirely inert to shock or detonation. When any combustible dust is suspended in sufficient concentration in air, it produces a potentially explosive mixture, since the conditions are then

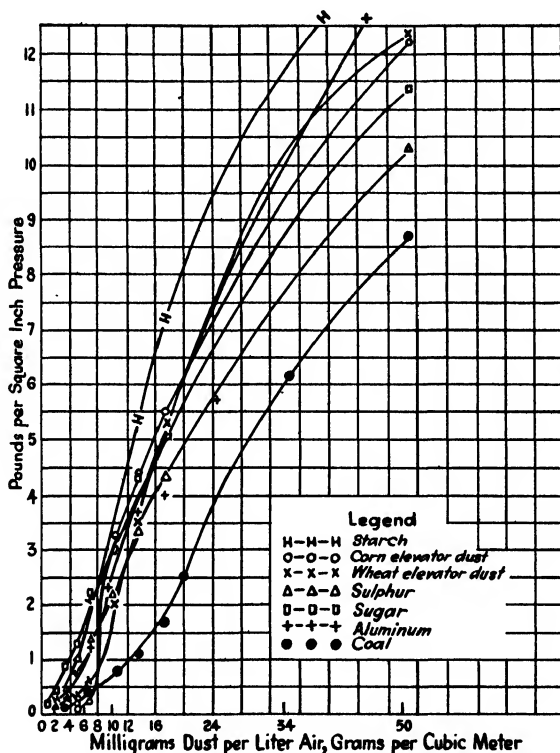


FIGURE 7. Relation of pressure developed, to concentration of various dusts in air when ignited by a glowing wire (Trostel and Frevert).

such that flame propagation from particle to particle can take place with explosive rapidity. Aluminum powder is not an exception to the rule.

Trostel and Frevert⁸ of the U. S. Bureau of Chemistry, and others^{4, 5, 6} have investigated some of the factors involved in dust explosions. Fig. 7 shows the pressures produced by the ignition of mixtures with air of the following dusts: starch, corn elevator dust, wheat

elevator dust, sulfur, sugar, aluminum and coal. The highest pressures, indicating most rapid combustion, were produced with starch. Aluminum powder was found to have a very high ignition temperature, 1700° F., but the high heat of combustion and the high temperature produced thereby promote rapid combustion once it is started. These authors report that at least 7 ounces of aluminum powder per thousand cubic feet of air are required before the mixture becomes explodable. This is the same value found for starch and sulfur. Van der Dussen⁹ found substantially higher values for the lower limit of explosibility of aluminum powder in air; they ranged from 32 to 175 ounces of aluminum per 1000 cubic feet of air, depending on the fineness of the powder.

The experimental determination of the minimum amount of aluminum powder which will explode when uniformly dispersed in air and ignited is a very difficult problem. The principal difficulty is in preparing a uniform air-suspension of powder of known concentration. The powder flakes tend to stick together in clumps and also to stick to the surfaces of the equipment and, once dispersed, promptly begin to settle out. High local concentration of the powder may also produce an explosive mixture next to the source of ignition, while the great bulk of the mixture is below the explosive limit. It is probable that some such condition as this was responsible for the very low limit reported by Trostel and Frevert. Recent unpublished experiments by R. B. Mason of Aluminum Research Laboratories have shown that the lower limit for explosibility is a uniform dispersion of about 50 ounces of fine aluminum powder per 1,000 cubic feet of air at ordinary temperatures. This value was arrived at as the result of a variety of measurements by several different methods. When nitrogen or carbon dioxide are mixed with the air to reduce the oxygen concentration, the lower limit of powder concentration is raised. When the oxygen concentration has been decreased to about 10 per cent, a mixture is produced which appears to be non-explodable.

Where aluminum powder is in continuous use, care should be taken to prevent the accumulation of dust. Naturally, flame and electric spark should be avoided in places where aluminum powder may be suspended in the air in appreciable quantities, or where it may be readily stirred up.⁴ These precautions are particularly to be observed in operations like lithographing and bronzing, where the powder may be used in dusting processes without liquid. When the powder is mixed with vehicle, as in aluminum paint, it constitutes no special hazard.

Do not put mixtures of aluminum powder with water in closed containers. Gas generation may produce substantial pressures and hazard. Washing aluminum paint residues out of a drum with soda solution may be hazardous, if these precautions are overlooked.¹

In storing aluminum powder in quantity, the following precautions should be observed: Keep the powder dry; in contact with water it may slowly react and heat as a result. In case of fire, *do not put water on aluminum powder*. Smother the fire with sand without disturbing any

powder which may be burning. Keep the premises clean and free from accumulations of aluminum powder as "dust" on ledges and other horizontal surfaces. With intelligent handling, the hazard in using aluminum powder is less, for example, than in handling the volatile thinners of the paint trade. Since, however, emergencies do sometimes arise, it is well to know how to care for them.

Any fire hazard from aluminum paste is less than from the storage of mineral spirits alone, since the contained liquid is held by the solid powder and will not flow extensively if a container is broken. When ignited, the volatile mineral spirits burn, but the aluminum powder does not become ignited until the liquid has all burned out. Even then, the powder seems to stick together in lumps which do not fly around like the dry powder, even when shaken or disturbed.

Aluminum is Non-Toxic.

A comprehensive survey of the literature dealing with the hygienic aspects of aluminum and aluminum utensils has been made by Dr. George D. Beal.² In addition to his survey of the technical literature, Beal himself has investigated the subject thoroughly in the laboratory. Based on all of his experience, he concluded that "aluminum is not a poisonous metal and does not give rise to any disease."

In at least one company manufacturing aluminum powder, periodic medical examinations are made of the workers. Over a long period of years, no toxic effect of aluminum powder has been observed. Recently, Tocco and Mulas have experimented with animals by feeding them controlled amounts of aluminum powder. Their conclusion is that aluminum powder is inert and harmless to the animal organism.⁷

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Chapter 3.

Examination of Aluminum Powder

Methods employed for the examination of non-metallic pigments can be used with aluminum pigment only in certain cases. Many of these methods are not applicable to aluminum powder because of its metallic character and the flake-like shape of the pigment particles. Other methods have had to be developed, therefore, to measure special characteristics. Substantial progress has been made in this direction and further developments are in prospect.

Qualitative Tests.

For many, if not most uses, the value of aluminum powder depends upon its appearance; or more exactly, its appearance after application. For this reason the human eye has been the most generally useful tool in examining and testing powder. The eye, however, has its limitations, and furthermore, provides no quantitative record of its observations.

About the simplest test which can be made is to dip the tip of ones' finger in the powder and then transfer some of this powder to a fingernail on the other hand. If two powders are to be compared, another finger may be employed to transfer some of the second powder to the fingernail next to the first one. The powder may also be "striped" on the palm of the hand instead of the fingernail. The principal points to be noted in examining the streaks of powder are the relative sizes and proportionate number of flakes. Some idea of differences in color and brilliance may also be obtained in this way. While a person by practice may become very skillful in such examination, the method has many limitations—and frequently leads to mistaken conclusions.

A somewhat more elaborate test is known as the striping test. A sample of powder is measured out and mixed with a standard volume of test liquid, usually a varnish. A soft camel's-hair brush is then filled with the mixed paint and applied in a single brushing stroke to a sheet of white glazed paper. Usually a second stripe is applied just below the first, using the paint left on the brush after the painting of the first stripe. The ease and completeness of leafing of the powder can be readily observed in the first stripe; particularly at the beginning, where the paint film is thickest. In this way a series of powders, made into paint, can be compared for differences in leafing, color, reflectivity and particle size. It should be remembered, however, that this method of examination is as much a test of the vehicle as of the powder, and the results will

vary with different vehicles. In order to make the comparison of value, the test conditions should be kept strictly comparable—a condition which is not readily maintained. Much can be learned, however, by skillful and intelligent application of such tests.

Chemical Analysis.

In a quantitative way, composition is one characteristic which can be determined with considerable accuracy. The aluminum employed in the manufacture of bronze powder ordinarily contains iron and silicon as impurities. The iron and silicon form constituents in aluminum which are blue to gray in color; they give commercial aluminum its bluish tinge. If present in excessive amounts, they will injure the color of the powder. Powder of the best grade is made from aluminum containing less than about one per cent of metallic impurity. A powder may also be off color as a result of contamination with "dirt" of some kind, so that a specification regarding purity of the metal used in powder-making will not necessarily insure the securing of a powder of satisfactory color. Unfortunately (or perhaps fortunately, as one may view the matter), the eye is a better judge of fine differences in color than is chemical analysis. Where chemical analysis is desired, the Tentative Methods of Chemical Analysis of Aluminum of the American Society for Testing Materials should be employed.^{3, 6}

From time to time specifications have been written for aluminum powder which specify that the copper content of the powder shall not exceed some limit, such as about 0.05 per cent. This requirement was frequently based on the belief that aluminum bronze powder containing appreciable amounts of copper would have an injurious effect on thin rubber films in which it might be incorporated, as for example, rubber-coated balloon fabrics. It is well known that metallic copper, under some conditions, has a very injurious effect in promoting the aging and deterioration of rubber. This knowledge probably prompted the writing of such a specification. Traces of copper *alloyed* with aluminum do not, however, behave like metallic copper because of their combination with aluminum, and practical tests have proven that copper alloyed with aluminum, at least up to about 0.1 per cent, is not injurious to a rubber film with which it is in contact. Sometimes, however, when aluminum bronze powder is made in a plant which also manufactures copper bronze powders, there may be contamination of the aluminum bronze powder by metallic copper, and such contamination would be undesirable in contact with rubber.

While it is said that copper bronze powder may cause some lacquers to gel, the presence of traces of copper alloyed with aluminum has not been found to have any such effect. In fact, aluminum powder does not cause gelling of lacquers.⁴

Chemical analysis is useful in detecting the presence of adulterants which cheapen the powder and injure its usefulness. Mica is the most

common adulterant employed. Its presence is very difficult to detect visually because of the high reflectivity, at certain angles, of the flake-like mica particles. They are injurious to the protective value of a paint because they are transparent to light. Mica is a complex aluminum silicate, commonly containing magnesium. Its presence can usually be detected by treating a small portion of the powder with dilute hydrochloric acid (1 to 5) with gentle heating until gas evolution ceases. The aluminum will dissolve, while any mica present will be practically insoluble under this treatment and remain as a residue which can be filtered off and examined. The filtrate should be examined for calcium to detect the presence of calcium carbonate if used as an adulterant. Generally, mica can be recognized by its flake-like form, especially if examined under the microscope at low magnification.

It is sometimes of interest to determine the amount of polishing medium (tallow, stearic acid, etc.) on the powder. The usual chemical method for a determination of this character is to place a weighed sample in an extraction thimble and extract with a suitable solvent, such as acetone.

In determining the acetone-soluble material in aluminum bronze powder, the method of test recommended by the American Society for Testing Materials (designated as D306-29T) may be followed.¹ The use of an extraction flask of the type illustrated is important, as it is essential that the powder be washed with *hot* solvent. It is also very important that the extraction be continued for at least 16 hours. Extractions for shorter periods seldom yield all of the soluble material. The acetone extract of a series of powders, domestic and foreign, was found to be between 0.5 and 4 per cent.

Another method commonly used for determining lubricant is to dissolve the metal in 2 g. of aluminum powder or paste by slowly adding 60 cc. of 1:1 hydrochloric acid, warming slightly to complete the reaction. The residue is filtered off and washed thoroughly with hot water. The grease is then dissolved from the filter paper and beaker by means of acetone, the solution collected and evaporated, and the residue dried at 110° C. for 1 hour and weighed.

Although a powder may be made from aluminum having a purity of 99 per cent, it will not contain 99 per cent metallic aluminum. Aside from the per cent or so of lubricant, the powder will contain aluminum oxide, resulting from the surface oxidation of the flakes during the stamping process. The oxide so formed may readily amount to several per cent.

The oxide content can be determined in several different ways. One method, which may be called the oxidation method, is to put into solution a weighed sample previously freed from grease; then precipitate the metal as hydroxide, and finally ignite and weigh as oxide. From the increase in weight, as the result of converting aluminum to aluminum oxide, the content of metallic aluminum can be calculated. Another method is to dissolve the sample in potassium hydroxide; the evolved

hydrogen is passed through a combustion train and collected and weighed as water. The hydrogen evolved and the metallic aluminum equivalent can then be calculated. In both of these methods, the oxide is determined by difference.

A method superior to either of the foregoing methods involves volatilization of the metallic aluminum as aluminum chloride and the direct determination of aluminum oxide in the residue. In carrying out this method, a 1-gram sample of aluminum powder, contained in a fused silica boat, is placed in a combustion tube arranged to be heated to a temperature of 375° to 400° C. in an electric furnace. A current of dry hydrochloric acid gas is then passed over the sample. The metallic aluminum is converted to aluminum chloride, which is volatilized and swept out of the tube into a condenser. The aluminum oxide, however, remains unaffected. Along with the aluminum chloride, a substantial portion of the other metallic elements is volatilized and removed. When the sample has been freed from metallic aluminum in this way, a rough approximation of the oxide content can be obtained by weighing the residue. An accurate determination is made by fusing the residue with potassium pyrosulfate, dissolving the fusion, and directly determining the alumina content by well-known methods.

Leafing Tests.

It is common observation that the speed and completeness of leafing will vary with different powders as well as with different vehicles. Some quantitative measure of these variables is very useful in comparing powders, vehicles and paints. A qualitative observation can be obtained from the striping test previously discussed. A quantitative method, which has proven very useful, has also been developed in the author's laboratories.

If a steel spatula is dipped into aluminum paint and then suspended to allow the excess paint to drain off, leafing of the powder in the paint film begins almost immediately. Leafing takes place most readily at the bottom end of the spatula, and gradually extends up the spatula with a speed and completeness depending upon the "leafing power" of the paint. If leafing is not complete, there will be a certain level on the spatula above which there will be obvious cracks and "breaks" in the leafed film. If the spatula was immersed to a depth of 10 cm. and, after a suitable time interval, the paint film has perfectly leafed to a height of 6 cm., then the paint may be said to have a leafing power of 60 per cent.

By standardizing the conditions of test, a useful method is provided. When testing powders, a standard vehicle is necessary, and when testing vehicles, a standard powder is necessary. For a standard test vehicle, there may be used a solution of 30 grams of powdered coumarone resin in 100 cc. mineral spirits meeting Federal Specification TT-T-291. This liquid was chosen to permit ready differentiation between the leafing properties of the so-called Varnish grade powders. None of these

powders will leaf 100 per cent in this test, although some of the finest Lining powders may appear to do so. To secure identical results with different spatulas, they should be carefully selected to have the same dimensions and then "standardized" by comparison tests. In order to make the test reproducible, the following dimensions have been selected as standard. The blade of the spatula must be not less than 5.5 inches long, and must have a width of 0.540 ± 0.002 inch. The thickness 1 cm. from the tip must be 0.013 ± 0.003 inch; at 10 cm. from

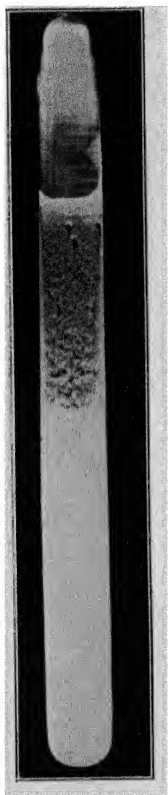


FIGURE 8. Appearance of leafing test spatula showing completely leafed area below and partially leafed area above; leafing power shown is about 63 per cent.

the tip, 0.038 ± 0.004 inch. In making the test, 25 cc. of the vehicle is thoroughly mixed with 4 grams of the aluminum powder to be tested. The test tube (6" long \times $\frac{3}{4}$ " I.D.) is filled with paint to give a depth of 100 mm. when the spatula is inserted. The temperature of the paint is held between 22° and 28° C., and the surrounding air temperature should be between 20° and 30° C. The test should be conducted in a draft-free location. The spatula is then dipped immediately into the freshly mixed paint until it touches the bottom of the tube. After rotating it gently for 10 seconds, the spatula is withdrawn and suspended vertically in

free space for two minutes. The height of the perfectly leafed area is then measured and expressed as a percentage of the total depth of immersion of the spatula.

In measuring the leafing power of fine mesh powders, it is frequently observed that the leafed area extends to the top of the immersed area but with a few breaks in the portion near the top. This generally indicates that more of the flakes are trying to leaf than the space provided permits. In comparing such powders, it is desirable to reduce the weight of powder sample taken, to 3.5 or 3 grams, for example. The results, of course, are not directly comparable with those obtained with a sample of different weight.

If a mixed paint is to be tested, obviously the standard test liquid is not needed. The standard test liquid as described above gives results comparable with those obtained with some of the vehicles now used for aluminum paint. However, many vehicles promote substantially better leafing of aluminum bronze powder than does this test liquid.

Screening Tests.

A good approximate idea of the distribution of particle sizes in the powder can be obtained by passing the powder through a series of standard screens. Sometimes no attempt is made to further classify the material passing through the 200-mesh screen. The extremely fine particles which should be present in substantial amount in aluminum bronze powder are of such importance, however, that the use of a 325-mesh screen is frequently advisable. A 400-mesh screen is now available for special tests, and interesting information may be obtained by the use of such a screen, although it is hardly suited for routine testing.

In making such screen tests, it is very desirable to use a standardized technique. The standard screen containing a 30-gram sample of powder, properly assembled and covered, should be held in some mechanical tapping device and shaken for a suitable period. Usually a nest of screens is employed; for example, 100-mesh, 200-mesh and 325-mesh screens. The results are reported in terms of the percentages of the powder passing through or remaining on each of the individual screens. For control work, a screening interval of 15 minutes has been found very satisfactory, since only a very small additional amount of powder is passed by an additional period of screening. Usually, however, if screening is continued for an indefinitely long period, an appreciably larger proportion of the powder passes through. The effective mesh opening of a screen is larger for a thin flake than for approximately spherical particles, like cement grains. A very thorough cleaning of the sieve is frequently necessary and may be accomplished by dipping it in acetone; the adhering powder floats out of the gauze and can be skimmed off.

A difficulty met with in the screening of aluminum powder is the aggrégation or sticking together of flakes. For example, a powder which

all passed through a 140-mesh screen during the process of manufacture may still show, on test, one-tenth of a per cent of powder retained on a 100-mesh screen. By the use of a suitable liquid, most of this remainder may be put through the screen.

In wet screening, the aluminum powder is washed through the desired screen by means of a stream of alcohol or mineral spirits until a standard end-point is reached, the last residue being brushed gently with a camel's-

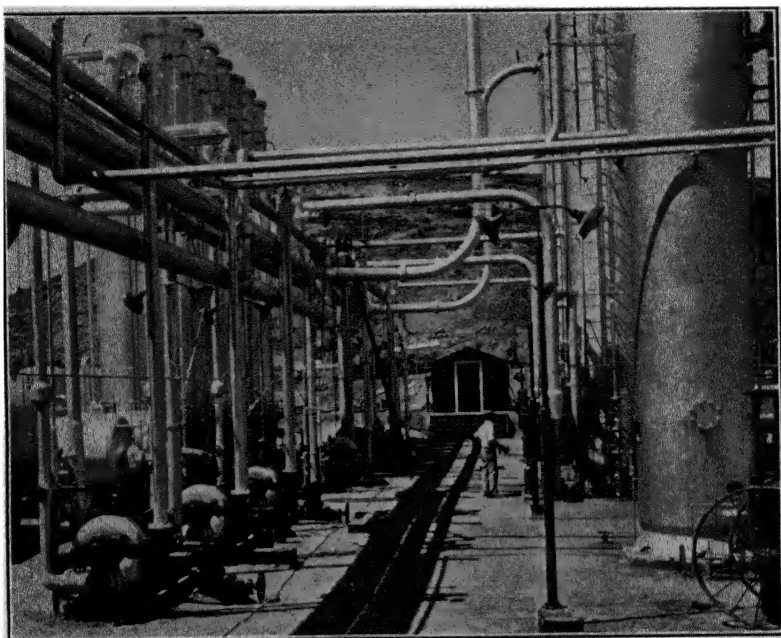


FIGURE 9. Natural gasoline plant at Kettleman Hills, California; aluminum paint protects equipment and reflects solar radiation. (Courtesy of Foster-Wheeler Corporation.)

hair brush to break up the agglomerates.² The wet screening method must be used, of course, in examining the mesh size of aluminum paste. The wet screening method generally results in passing more powder through a given screen than does the dry screening method. It is also difficult to check results by the wet screening method, because of variation in individual judgment as to the end-point.

Apparent Density.

Specification No. 388-1930 of the British Engineering Standards Association⁵ describes a "Method for the Determination of Settling Properties," which involves shaking up 10 grams of the powder with 35 cc. of benzol in a standard 50 cc. stoppered measuring cylinder. After

being well shaken, the mixture is allowed to stand undisturbed for a period of 18 hours. The requirement is that at the end of this period the volume occupied by the powder shall be "not less than 12 cc."

The results of such measurements seem to be an approximate index of the relative bulk or apparent density of different samples of powder. For example, a particular powder showed by this test a settled volume of 18 cc. Assuming a density of 2.5 for the metal flakes themselves, the actual volume of the 10 grams of metal was 4 cc. The difference, of course, between 4 cc. and 18 cc. would be attributable to the voids between the flakes. Long standing (more than 18 hours) in the liquid, however, does not decrease the apparent volume occupied by the powder.

On the other hand, if the apparent density of the same powder is determined by gentle tapping in an evacuated cylinder until it reaches a minimum volume, the 10 grams of powder are found to occupy a volume of 12.5 cc. As a measure of the apparent density of the powder, it is felt that the latter method is a more satisfactory one. The powder sample is placed in a measuring cylinder which can be evacuated. The evacuated cylinder and contents are then tapped gently until the powder settles to a constant volume, which is measured. The smaller the flakes and the thinner they are, the lower is the apparent density of the powder.

In this country some use has been made, for control purposes, of a settling test in which alcohol is used as the medium in which the powder is dispersed and allowed to settle. In tests of this character, the volume to which the powder settles is determined by a variety of factors, such as the physical size and shape of the flakes, as well as the characteristics of the liquid in which the powder is shaken. When shaken with alcohol, aluminum powder flocculates to a marked degree and settles cleanly in the liquid with a sharp line of demarcation between the clear, supernatant liquid and the settled powder. In one such test, 15 grams of powder are to be shaken with 50 cc. of denatured alcohol in a standard 50 cc. graduated cylinder. The powder is then allowed to settle until constant volume is reached and the settled volume of the powder calculated in terms of pounds per cubic foot. Mineral spirits may also be used as the settling liquid.

The laboratories of the Air Corps, Wright Field, Dayton, Ohio, have used a similar test which measures—not the final volume to which the powder settles after an extended period—but the rate of settling of the powder after shorter periods of 2 to 30 minutes. The rate of settling in such a test appears markedly influenced by the number of flakes and their physical dimensions, so that this test can be employed to differentiate approximately between various grades of powder. For example, when 10 grams of two grades of powder were each shaken with 100 cc. of neutral denatured alcohol (specific gravity 0.820 ± 0.002 , at 25° C.) in standard 100 cc. glass-stoppered graduates, and allowed to settle, the settled volumes of the two powders, after various intervals, were found to be as follows:

TABLE 2.
RATE OF SETTLING OF ALUMINUM POWDERS IN ALCOHOL.

Time of Settling	Varnish Grade	Lining Grade
5 minutes	88 cc.	98.5 cc.
10 minutes	73 cc.	97 cc.
15 minutes	61 cc.	94 cc.
30 minutes	37 cc.	84 cc.

Of course, the test can be continued until no further settling of the powder is apparent and a figure arrived at for the apparent density of the powder, under these conditions.

The volume to which a powder settles may vary quite widely with different powders of the same mesh size, as well as with powder of different mesh sizes. The number of flakes in a unit weight is an important factor in determining this apparent density.

Covering Area on Water.

The method described on page 18 for determining the average thickness of flake has been developed into a standard procedure for determining what may be called the covering capacity or covering area on water of aluminum powder. The method is based on the fact that if all the flakes in a given weight of powder are spread out in a film one flake thick on a surface of water and closely packed so as to eliminate voids between the flakes as far as possible, then the area covered is a measure of the thickness (or thinness) of the flakes. The results of the measurements are expressed in terms of the area in square centimeters covered by a gram of powder, and this value is termed the covering area. It should not be confused with the so-called covering power (square feet per gallon) of a paint. Dr. Mason and the author have published the following description of this method.⁷

It has been found most convenient to carry out the test in a shallow rectangular pan about 14 cm. wide, 60 cm. long, and 1.3 cm. deep. The vertical walls are about 1.3 cm. thick and are machined and finished smooth on the upper surface to insure good contact with the plate glass barriers. Two pieces of heavy plate glass about 2.5 cm. wide and several centimeters longer than the width of the pan are used to confine the surface film and to work the powder uniformly over the surface of the water. Before each determination, the upper edges of the pan and the plate glass barriers should be rubbed with a piece of ordinary paraffin and the glass plates polished with a clean cloth. Water is poured into the pan until the surface is appreciably above the upper edges of the pan. The paraffin-coated edges of the pan prevent the water from overflowing. Reasonable care should be taken to make sure that the height of the water surface above the edges of the pan is always the same.

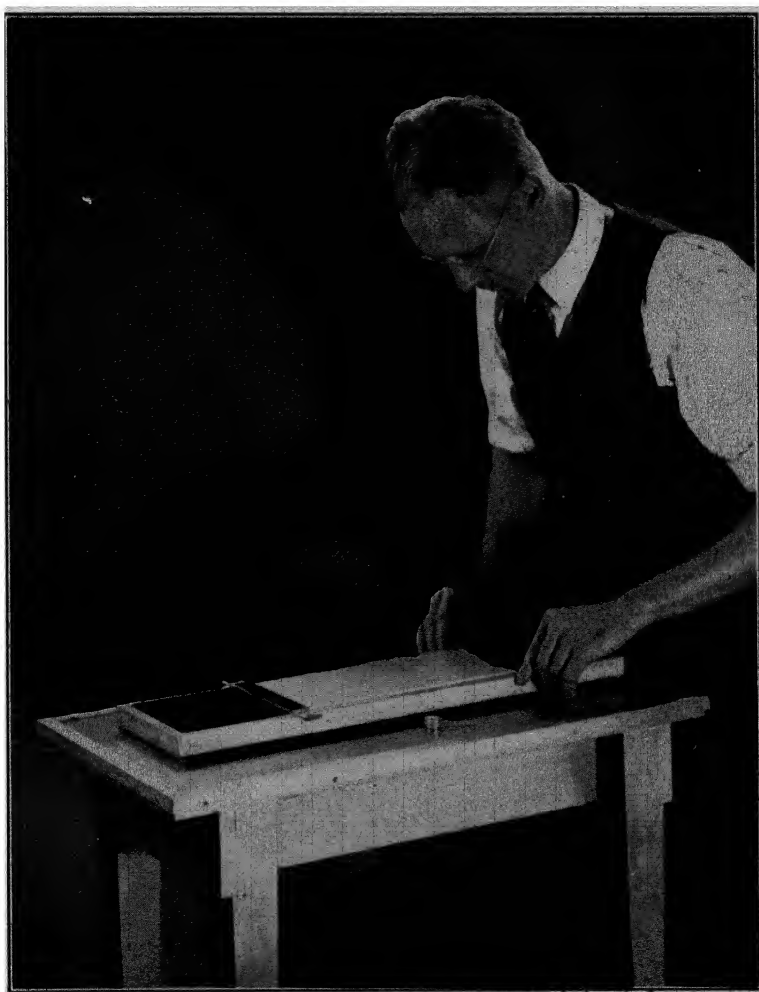


FIGURE 10. Apparatus for determining the covering area of aluminum powder on water, showing method of manipulation of plate glass barriers.

The surface of the water in the pan is swept from end to end with one of the glass plates to remove the major portion of surface impurities, such as dust or grease. One of the glass plates is then laid across the pan near one end. Any surface impurities remaining are blown away from the water surface near the first glass barrier and the second glass plate is laid across the pan near the first, taking care that no impurities get between the two plates. The second barrier is then pushed nearly to the other end of the pan, sweeping all impurities before it. It is best to remove these impurities from the surface between the barrier and the edge of the pan by sweeping them over the edge of the pan with a piece of filter paper. The reason for doing this, is some of these impurities might creep under the barrier as it is moved back and forth and cause breaks in the powder film which is to be distributed on the clean water surface between the two barriers.

The two glass barriers are left near the ends of the pan with the clean water surface between them. An accurately weighed sample of powder is then carefully distributed upon the clean water surface. A small aluminum bottle cap makes a suitable container for weighing the aluminum powder. The powder is poured carefully from the edge of the weighing container directly onto the water surface, care being taken not to get too much powder in one place. The above operations should be carried out in a draft-free room.

After the powder has been distributed on the water surface, one of the glass barriers is pushed towards the other end of the pan, sweeping the powder before it for about two-thirds the length of the pan, and then pulled back again. This pushing and pulling operation is repeated until the powder surface is smooth and free from breaks. Leaving the first barrier in its original position, the second barrier is then moved back and forth in the same manner. The two barriers are then adjusted until there are no breaks in the metallic film and wrinkles start to form near each barrier because of too great pressure. One of the barriers is then moved back until all the wrinkles at both ends of the film are removed. This barrier is then adjusted by increasing the pressure enough to form a few wrinkles and then decreasing the pressure just enough to smooth out the wrinkles. The barrier at the other end is then adjusted slightly. The length of the film between the parallel barriers is measured. The barriers are again worked back and forth three or four times and after adjusting as before, the length is measured for a second time. This procedure is repeated until the length of film remains constant for three consecutive measurements. Knowing the weight of the sample and the length and width of the metallic film, the area which one gram of powder will cover can be calculated.

Fig. 10 shows the test equipment and illustrates the method of manipulating one of the plate glass barriers. The film of powder is shown well worked out on the surface of the water between the barriers. The

small cup used for weighing the powder and distributing it over the water appears on the table just in front of the rectangular pan.

The weight of powder taken will depend on the size of the pan and the grade of powder used. For the pan described in this paper, a sample of Standard Varnish powder weighing about 0.1 gram is satisfactory. When Lining powders are used, a sample weighing 0.05 gram or less will be sufficient. It is preferable that not more than about three-fourths of the cleaned water surface of the pan be covered with the powder film. Experience teaches the operator the size of sample necessary for the pan used. About 15 to 20 minutes are required for making each covering

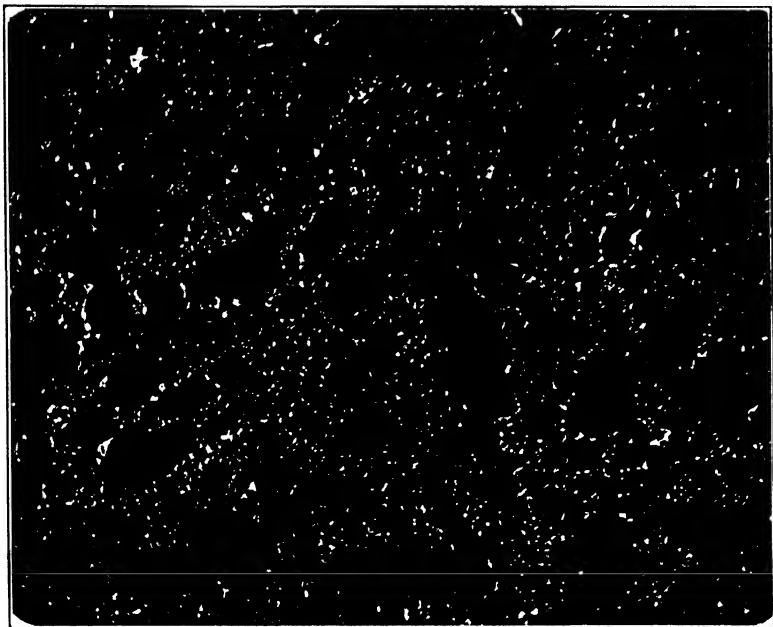


FIGURE 11. Photomicrograph (magnified 100 diameters) of compressed film of aluminum powder, one flake thick, on water. Black areas are aluminum.

area measurement. A skilled operator can make duplicate measurements on the Standard Varnish grade of powder which will not differ in area by more than about 50 sq. cm. for 1 gram of powder. Since 1 gram of this grade of powder will cover about 4,000 sq. cm. of surface, the method is reproducible to within about 1 to 2 per cent.

When pressure is applied to the uniformly distributed powder film by moving one of the glass barriers, it first wrinkles and then folds up as more and more pressure is applied. As the pressure is reduced the film unfolds to a uniform surface. This procedure can be repeated again and again without disrupting the film. It appears as if only the lower side of each powder flake was wet with the water. A microscopic

examination of a well worked powder film shows that it is, for all practical purposes, only one flake thick.

In Fig. 11 is shown a photomicrograph of the aluminum powder film while on the water and compressed for measurement. The photograph was taken with transmitted light and any voids appear as bright spots in the picture. An approximate estimate is that less than about 3 or 4 per cent of the area appears as voids uncovered by powder.

The covering area of various grades of aluminum powder will range from about 3,000 to 25,000 sq. cm. per gram of powder, although both higher and lower values are obtained. The low range of values is obtained with the so-called "varnish" grades of powder and the higher values are obtained with some of the Lining powders. Bronze powders are usually screened during manufacture in order to limit the maximum size of particle present in any grade. Even though a screen analysis may indicate that a series of powders are very close together in mesh size, the covering test may demonstrate a considerable variation in average thickness of flake. In Table 3 are given data on a series of powders obtained from different commercial sources. They are graded about the same commercially, both on mesh size and appearance, but the maximum covering area exhibited is about 70 per cent greater than the

TABLE 3.

COMPARISON OF COVERING AREA ON WATER AND MESH CHARACTERISTICS OF ALUMINUM POWDERS.

Sample	Covering Area sq. cm./gram	Screen Analysis		
		On 200-mesh screen per cent	On 325-mesh screen per cent	Through 325-mesh screen per cent
1	3040	16	30	54
2	3440	15	29	56
3	3720	12	32	56
4	4720	16	28	56
5	5260	17	28	55

minimum. While high covering area is, in general, a desirable characteristic, the conclusion does not necessarily follow that the highest covering area is always the best, as other characteristics must be considered in the evaluation of a powder for any particular use.

The covering area of the pigment in paste can be determined by extracting the liquid with acetone, drying the powder, and dusting the dry flakes on the water in the manner just described. The grades of paste now being manufactured show high covering areas, ranging from 12,000 to 25,000 sq. cm. per gram, depending on the grade under examination.

While for most purposes, the covering area expressed in square centimeters per gram is sufficient, the calculated average thickness of flake is also of interest. The real density of aluminum bronze powder is about 2.5 grams per cc., and covering areas of 3,000 to 12,000 sq. cm. per gram correspond with a flake thickness of about 0.0013 to 0.0003 mm. (0.000050 to 0.000012 inch).

Examination under the Microscope.

One difficulty in examining aluminum bronze powder under the microscope is to secure a uniform dispersion of the flakes on the glass slide. An excellent means of accomplishing this is to spread the aluminum powder to a one-flake film on a water surface just as is done in the

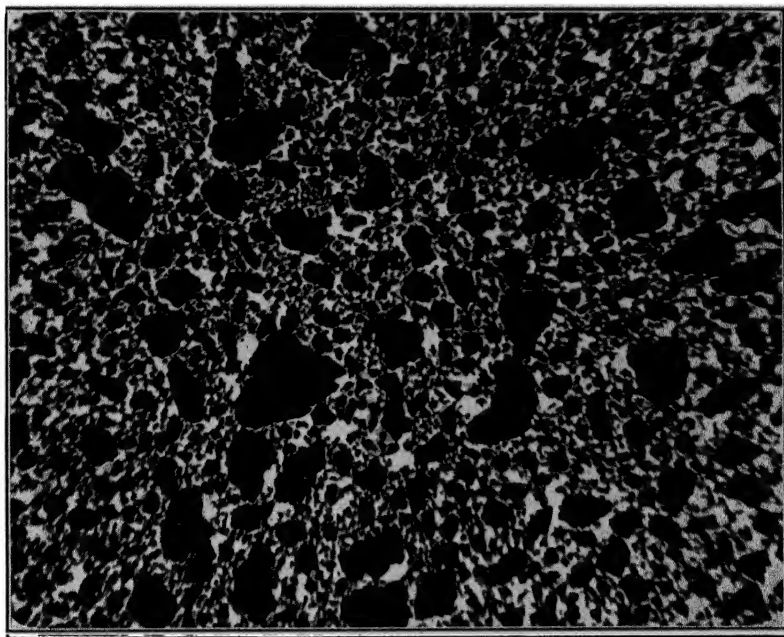


FIGURE 12. Photomicrograph (magnified 100 diameters) of expanded film of aluminum powder after transference from water to glass slide. Black areas are aluminum

method for determining covering area. The pressure on the metallic film is reduced so that the flakes are separate from each other. One end of a cleaned microscope slide is then dipped into the water and the slide immersed for about three-fourths of its length. The slide is then carefully raised under the powder film and withdrawn from the pan. A uniform film of powder adheres to the glass slide and this is allowed to dry on the glass. Fig. 12 shows a photomicrograph, taken by transmitted light, of a film of powder spread on a glass slide by this method. The

film is not compressed and shows the individual flakes spread out and not touching.

Opacity.

The hiding power of aluminum paint is so high that any colored surface is usually completely obscured in one coat. Many of the methods applicable to the determination of the hiding power of non-metallic paints are not suitable for use with aluminum paint. Opacity, which is a somewhat related property of a paint, is a matter of considerable importance in connection with aluminum paint, since the ability of the aluminum powder to protect the vehicle against light by forming a highly opaque film is a partial measure of the relative durability of such a paint. The opacity of aluminum paints made with different powders may vary widely because of variation in the dispersion of the powder in the paint film. Usually powders with high covering area on water give paint films of high opacity.

A relative measure of opacity can be obtained by flowing out aluminum paints on glass or cellophane. Flow-outs on cellophane have the advantage of occupying little space and can be readily filed for future reference. The cellophane may be attached by paper clips to a thin metal sheet while the flow-out is being made. Flow-outs, to be comparable, should always be made under the same conditions. For example, the paints should be of the same consistency, the panels should be inclined at exactly the same angle, and approximately the same amount of paint poured on each panel, in order to secure paint films of the same thickness for comparison. After the films have dried, they may be compared by holding them in front of a bright light.

Testing Aluminum Paste.

In testing aluminum paste, many of the methods already discussed may be employed, although in some cases a different technique may be required.

When examining a paste for mesh size, the dry screening method, of course, is impractical. Wet screening, using alcohol or mineral spirits as the wash liquid is the method employed, as has been noted.

The leafing power is determined by the same method as that described for dry aluminum powder, except that a smaller sample of paste is mixed with the standard test liquid.

The percentage of metal in a paste may be determined approximately by heating a weighed sample at 100° C. until it reaches constant weight (24-48 hours). The residue consists of the metal powder and some of the polishing agent. This method would have no value, of course, where the wetting agent was not all volatile. A paste, containing from 63 to 65 per cent metal meets most commercial requirements, although some pastes run even higher than this in metal content.

If the paste liquid is extracted with acetone, the covering area of the aluminum flakes can be determined in the manner previously described by dusting the dry flakes on water.

Color and Brilliance.

The term "color" is frequently quite loosely applied in describing aluminum powders. Fundamentally, there is very little difference in

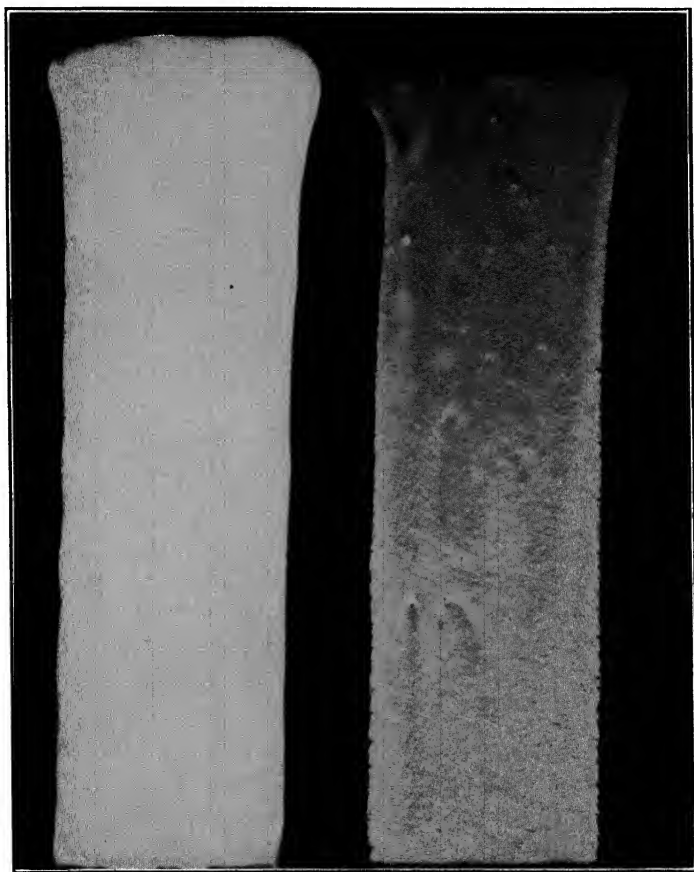


FIGURE 13. Print made using flow-outs of aluminum paint and gray enamel paint on cellophane as a negative; whiteness of the print is a measure of the opacity of the paint film on the cellophane.

the spectral color of aluminum bronze powders of various manufacture. Nearly all of them have the characteristic blue-white, metallic appearance of aluminum. The appraisal of color is commonly confused with

the brilliance or reflectivity of a powder or a paint film. Substantial differences in brilliance or reflectivity can exist without appreciable difference in the color of a powder or a paint film. Moreover, the apparent brilliance appears to change decidedly with change in the relative proportions of diffuse and specular reflection from the surface. As the proportion of diffuse reflection increases, the powder or the paint film made from it may appear, in common parlance, to become "whiter."

The exact comparison of differences in brilliance of different samples of powder presents special difficulties. If the comparison is to be made between the dry powders, it is quite essential that they be examined under conditions as nearly identical as possible. Merely looking at the powder in a container may be quite deceptive. The best practice is to place two small but equal piles of powder side by side upon a sheet of paper. Then by lifting the two edges of the paper so as to give it a trough-like form and gently tapping, the two piles of powder may be shaken down into exactly the same size and shape. If they are placed close together before shaking, they will touch each other and form a line of separation which should be carefully observed in deciding as to their relative brilliance.

Quantitative measurements of brilliance or reflectivity can, of course, be made upon paint films, but in this case there are involved various factors of paint preparation and application which may interfere to make the comparison of powders an inexact one.

Reflectivity.

The reflectivity of aluminum paint films can be measured with satisfactory precision by means of the Taylor reflectometer, which was developed at the Bureau of Standards.¹¹ The photometric measurement is made with a Macbeth illuminometer attached to the reflectometer. This method measures the total reflecting power of the surface under illumination. It requires a test piece three or four inches square for measurement; the necessary observations can be made in five to ten minutes.

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- ⁹ Federal Specification TT-T-291, "Thinner; Paint, Volatile Mineral Spirits"; March 31, 1931.
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Chapter 4.

Composition of Aluminum Paint

Aluminum paste and powder are unique paint pigments. When mixed with a suitable varnish vehicle, they form paints having an unusually serviceable combination of properties such as high opacity, high reflectivity, low emissivity, high moisture-proofing efficiency and great durability. Unlike most other pigments, aluminum powder does not need to be ground in oil, and in fact is usually injured by grinding. Stirring together of aluminum pigment and vehicle, to form a uniform suspension, is all that is required to prepare the paint for use. It can then be applied like other paints, either by brushing or spraying. With a suitably chosen vehicle, it can be applied generally on metal, wood, cement and concrete, brick, stone, etc., and is remarkable for the many specific applications it has.

Compared with many paints, the use of aluminum paint is a strictly modern development. Although aluminum bronze powder has been available for the past 25 to 50 years, its extensive industrial application is a development of the last 15 years. Aluminum paint spent its infancy, so to speak, in decorating picture frames and radiators. That it had a larger industrial use was not appreciated until research had determined the proper composition for use for various purposes and established its resistance to weathering, as well as its other valuable properties.

In preparing aluminum paint, a generally satisfactory method is for the user to mix aluminum paste or powder and vehicle in the proper proportions as needed and then to apply the paint promptly, preferably the same day. Maximum leafing, brightness and hiding power are generally secured when the paint is *not* allowed to stand for an extended period after mixing. The advantages of mixing aluminum paint as it is used are such that the method is widely employed. To secure the best results, it is obvious that both vehicle and powder should be adapted to the job in hand. The selection of a vehicle must be made with special reference to the behavior of the powder in it and the performance of the mixed paint on the surface to be painted.

Vehicle Requirements.

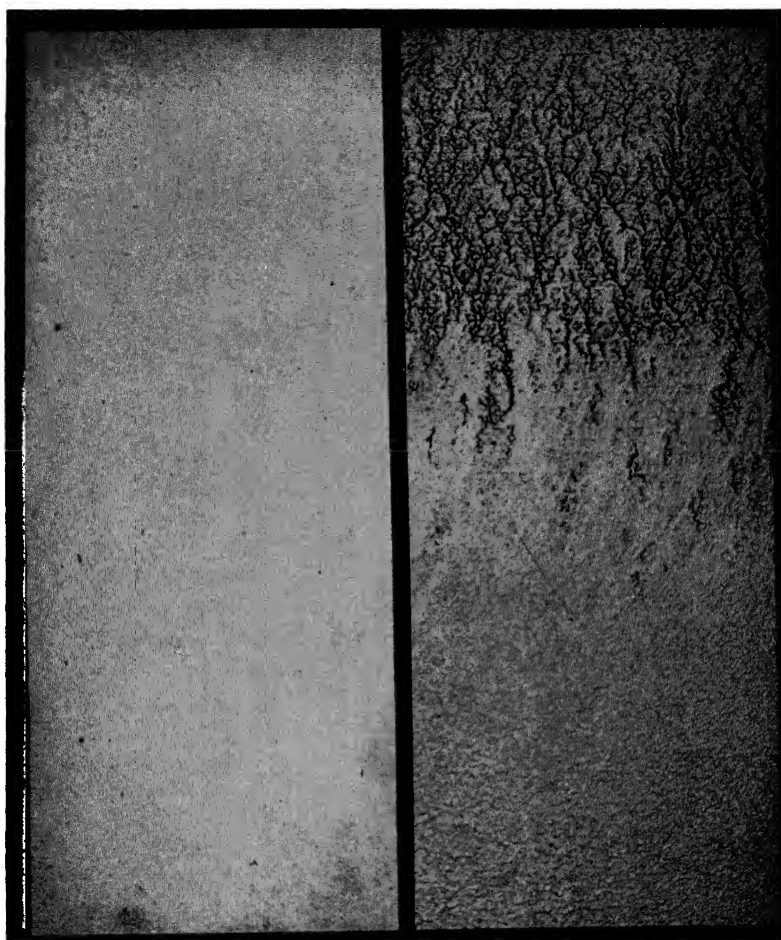
The general requirements for the vehicle are, that when mixed with the "proper amount" of pigment, the paint shall spread and cover satisfactorily, have a satisfactory appearance, dry to a tough, durable film, and exhibit the expected protective action. The first requirement of a

vehicle, therefore, is that it shall have the proper "body" or viscosity. The painter, by spreading the paint with a brush, can very quickly decide whether it flows and levels properly. If the paint is too thin, it will not hide and protect satisfactorily, and if too thick, it cannot be spread out to a uniform film of the right thickness without excessive effort in brushing. Within these extremes there is a range sufficiently broad to meet the individual preference of nearly every user. The method of application will frequently be a factor in determining the proper consistency of the paint. Applied by spraying, for example, a slightly lower viscosity is generally desirable than for brushing. It is not sufficient that the vehicle have the desired viscosity. The mixed paint must also have a sufficiently high yield value and plasticity so that, when applied to a smooth, vertical surface, it will not run, sag, or break, but will set and dry to a smooth, uniform film.

Difficulties with Raw Linseed Oil.

These considerations are very clearly illustrated when raw linseed oil is used as a vehicle for aluminum paint. Raw linseed oil has a viscosity as high as some other liquids which make satisfactory vehicles for aluminum paint. Nevertheless, aluminum powder mixed with linseed oil cannot be applied to smooth vertical surfaces without running and breaking. This is forcibly illustrated by Fig. 14, which shows the results of painting a vertical steel panel with such a mixture. The paint has not a sufficiently high yield value to remain in place, nor does it set sufficiently rapidly by drying to prevent a substantial amount of the paint running down to the bottom of the panel. However, on a rough surface, and particularly on a rough and porous surface, such a paint may not show this breaking and sagging. The liquid vehicle alone is said to be "viscous," that is, it flows or deforms at a certain rate under the slightest stress. The mixture of powder and vehicle should, however, be plastic and not flow until a certain critical pressure or "yield value" is reached. Obviously, a paint which is applied to a vertical surface should be sufficiently plastic so that it will not run or streak, but yet will level out to a smooth film.

The setting of the paint film is aided by the presence in the mixture of some volatile liquid. The ready evaporation of thinner from the paint film naturally "thickens" the remaining material and helps hold it in place until the drying of the film has progressed sufficiently to accomplish this. In the case of raw linseed oil used without thinner, there is no volatile matter to evaporate and the aluminum paint made with it is generally too fluid to set properly. In order to use linseed oil it becomes necessary to "body" it by some such method as heating and oxidation. Ordinary boiled linseed dries somewhat better than raw linseed oil, but is not bodied appreciably and has the disadvantage of giving a soft film and permitting dirt adherence to an objectionable degree. Such a film is also low in moisture resistance and is of no commercial importance.



Aluminum paint made with bodied
linseed oil.

Aluminum paint made with raw
linseed oil.

FIGURE 14. Behavior of raw linseed oil and bodied linseed oil in aluminum paint applied on vertical steel panel.

However, the group of oils known as “bodied” oils are more satisfactory in respect to consistency and have some applications. An aluminum paint film made with bodied linseed oil is shown in Fig. 14.

Bodied Oils.

Linseed oil may be bodied in two ways. One method is to heat linseed oil under carefully controlled temperatures of about 575° to 600° F. for a number of hours, depending on the consistency required. The product is known as “heat bodied” or “kettle bodied” linseed oil and

is of syrupy consistency. A somewhat quicker method is to blow air through the oil during heating, so as to accelerate the oxidation process which thickens the oil. Such an oil is known as a "blown" or oxidized linseed oil. Usually a properly bodied oil will require dilution with from 30 to 60 per cent thinner to reduce its consistency to the proper value for aluminum paint. The appropriate amount of drier must also be added to make it suitable as a paint vehicle; the drier is frequently incorporated during the cooking of the oil. The heat-bodied oils make durable vehicles for aluminum paint, but are relatively slow drying and give soft films. Their use has been largely superseded by the long oil varnish.

A kettle-bodied oil bears a significant relationship to a long oil varnish, since as the gum content of the varnish is reduced it approaches a kettle-bodied oil in composition and properties. In fact, kettle-bodied oils are sometimes known as varnish bases or "all-oil varnishes." In addition to linseed oil, they may also contain tung oil in varying amounts. The incorporation of tung oil with linseed oil in a bodied oil vehicle is advantageous, in that it gives a harder and more rapid drying film, and some use is made of such a vehicle for aluminum paint.

Varnish Vehicles.

Varnish may be said to be the universal vehicle for aluminum paint. The term "varnish" is, however, very inclusive, and the manufacture of varnishes satisfactory for aluminum paint has become something of a special art. The varnishes which are of primary interest in this connection are usually mixtures of vegetable drying oil, resin, drier, and volatile solvent which have been compounded by heating and mixing to produce liquids which, when applied in thin coats, dry to tough, transparent, and more or less distensible films. A wide variety of oils may be employed, although tung oil (Chinawood oil), linseed oil, and perilla oil, as well as mixtures of these oils, are most commonly employed. The proper use of tung oil gives improved drying and moisture-proofing characteristics to the varnish. The resins may be the natural resins, such as Congo, Kauri, Manila, Pontianak, etc., or one of the wide variety of synthetic resins. One of the most commonly used artificial resins is ester gum, which is ordinarily made by esterifying rosin by heating it with lime and glycerine under suitable conditions. Different types of ester gums may be produced by esterifying other acid resins with polyhydric alcohols other than glycerine. Another group of resins is made by polymerization, and among the important materials of this character are the paracoumarone resins.

A useful group of synthetic resins results from various applications of the phenol-formaldehyde condensation reaction. The resinous product of the phenol-formaldehyde condensation reaction so widely used in plastic molding, when subjected to heat and pressure, sets to an infusible and insoluble substance. This insoluble resin is of little interest to the

varnish maker. Means have been discovered, however, of producing phenolic condensation resins which are oil-soluble and oil-reactive. These resins can be used alone in varnish formulation or combined with other natural or artificial resins. When properly used, these resins impart to varnishes some very desirable characteristics which are of value in vehicles for aluminum paint, such as rapid and thorough drying, good moisture and chemical resistance, and durability under severe exposure conditions.



FIGURE 15. Washington Crossing bridge at Pittsburgh; protected with two finish coats of aluminum paint made with Standard Varnish powder in long oil varnish.

Another group of the synthetic resins, termed the alkyd resins, is represented by the reaction products of polyhydric alcohols and polybasic acids or anhydrides, of which the most important are glycerine and phthalic anhydride. When a drying oil or its acid base is added to the mixture of glycerine and phthalic anhydride and caused to react therewith, the product is an oil-modified glycerol phthalate resin of unique properties. The product, under some conditions, may be a liquid oxidizable resin suitable for use as a varnish after thinning with a suitable solvent. It may also be a plastic oxidizable resin which is commercially supplied in solution in a suitable solvent and is mixed with oil or varnish in formulating vehicles for aluminum paint. These resins also make varnishes which dry quickly and thoroughly and are durable under severe exposure conditions.

Synthetic resins of the phenolic condensation type and the alkyd group, as well as combination types are legion.¹⁷ They are available

in innumerable degrees of color, hardness, solubility and other properties, so that any comprehensive description would be a volume in itself. A different type of resin, called Pliolite resin, has been produced from crepe rubber. This resin has been used in formulating aluminum paint vehicles which are said to be particularly adapted for use on hot surfaces such as vulcanizers, ovens, etc.⁸ Still another type, a chlorinated rubber resin, known to the trade as "Tornesit," has been used in varnish vehicles for aluminum paint.⁴ This sketchy outline of resins is intended only as an introduction to their use in aluminum paint, leaving any description of their detailed properties or of other useful resins to the published literature and to the manufacturer.

Vehicle Characteristics.

The vehicle should permit free leafing of the aluminum powder. The cooking, as well as oil, resin, thinner and drier may all play a part in determining the leafing characteristics of the powder, and little specific help can be given in this direction.

Experience has indicated that a long oil varnish should have sufficient metallic drier incorporated so that it will set to touch in about 2 to 6 hours and dry hard in about 24 hours. The opinion is also held by some that lead drier adversely affects the color and luster of the pigment in a *ready-mixed* aluminum paint. It therefore seems advisable to keep the quantity of lead drier used to a minimum. Where, however, the aluminum paint is to be mixed as needed, the presence of lead drier is not objectionable, and its use is quite customary. The thorough and rapid drying of aluminum paint films may also be favorably influenced by the suitable use of certain synthetic resins and oils such as tung oil.

The first essential for a varnish is that it shall have the proper consistency; the same considerations that were discussed in connection with linseed oil apply here. When aluminum paste pigment is employed instead of dry powder, it is desirable to use a vehicle of higher viscosity in order to compensate for the thinning action of the mineral spirits in the paste. Having a varnish of proper consistency and drying time, attention should then be given to the properties of the dried varnish film. For durability, particularly where exposed to sunlight and weather, a tough film is desired with considerable resistance toward moisture, smoke and the corrosive conditions of industrial regions. While the manufacture of varnishes, long an art, is now being brought under close chemical control, chemical analysis can still tell us very little about their properties, especially durability. The user must therefore depend on the recommendations or experience of the makers, or select vehicles as the result of physical tests made on the varnish film.

For ordinary interior use (not involving any special corrosion problem, for example) a satisfactory aluminum paint can be made from almost any good varnish of the proper consistency. For exterior use,

where resistance to sunlight, air, water, smoke and fume is necessary, a special type of varnish is required which will give a tough, durable film. Such varnishes are designated as long oil varnishes, spar varnish, water-proof varnish, etc., and are usually characterized by having a much higher ratio of oil to gum than is found in interior varnishes. A high percentage of oil gives the varnish film distensibility and life, while the gum in suitable proportions adds toughness and water resistance.

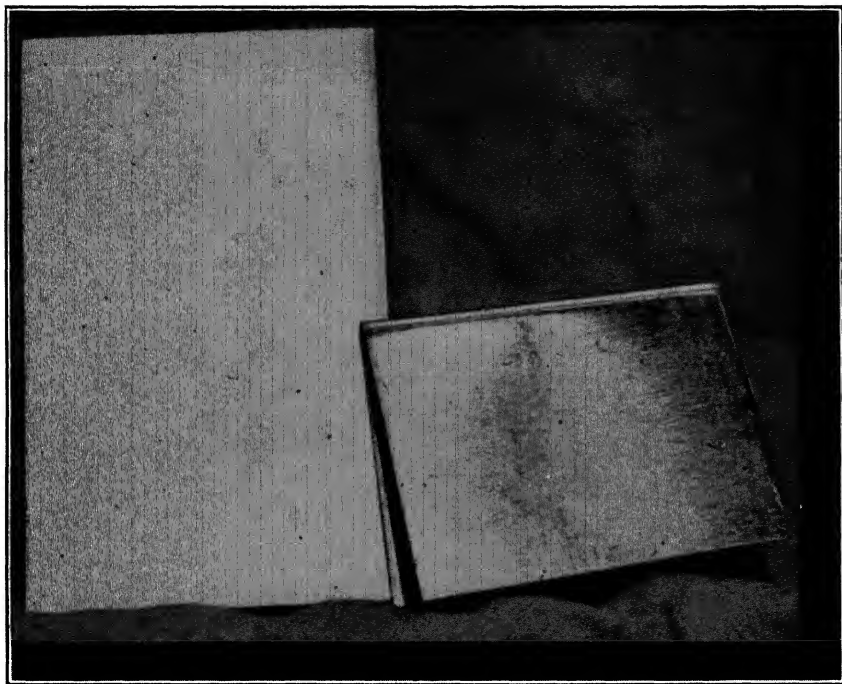


FIGURE 16. Kauri reduction test panel, before and after bending.

Another requirement is that the proportion of volatile thinner be not too high. The thinner evaporates completely from the paint film, leaving only the non-volatile oil and gums to serve as a binder for the aluminum bronze powder. H. A. Gardner ⁸ has investigated this factor and his conclusion is very much to the point:

"Greater durability was, as a rule, obtained from varnishes of fairly high non-volatile content, and by varnishes that had a substantial body. Varnishes of fairly high viscosity form films that are thicker than those of low viscosity. Consequently, the former usually wear for a longer period of time. It is conceivable that a varnish could be made, that would pass all the specifications of the Federal Specifications Board, and which would still be of very

thin body. Such a varnish, when brushed out, would present such a thin film that it might not be durable upon exposure."

It is also a general rule, based on experience, that the tougher varnish films are, the more durable. Of course, in a strict comparison, questions of composition and treatment are very important, but nevertheless, the generalization is remarkably useful in comparing varnishes. L. V. Pulsifer¹² developed the Kauri Reduction Test as a means of measuring the "elasticity" or toughness of a varnish and also its probable durability. The Kauri reduction test is conducted by determining the maximum percentage of a standard run-Kauri solution which can be added to the varnish and still give a film which, after baking on tinplate, can be bent over a $\frac{1}{8}$ -inch rod without cracking. The addition of the Kauri gum solution reduces the toughness of the coating. Mr. Pulsifer says that:

"Elasticity is the most important factor for determining the service durability of a finishing varnish, and, other things being equal, the comparative durability of a series of varnishes will follow exactly their comparative elasticity. This factor may be successfully estimated in the laboratory by the use of the so-called Kauri Reduction Test for Elasticity. This test was developed by the writer a number of years ago as the culmination of a long-extended and comprehensive series of experiments looking towards the perfection of a laboratory method for rapidly and accurately estimating the elasticity factor in a varnish. This test for elasticity was adopted by the Government during the World War for determining the elasticity of varnishes offered for airplane use, and for eliminating those considered too inelastic for the purpose. It has since appeared in numerous specifications to replace the former slow and unsatisfactory panel exposure test."

Came, working at the National Bureau of Standards, compared the Kauri reduction tests with the durability of spar varnishes in accelerated weathering tests and on outdoor exposure.³ He noted that:

"Of the poorest 15 varnishes, as shown by the outdoor exposure, none passed a Kauri reduction test of over 40 per cent, and of the 15 best varnishes, as shown by the outdoor exposure, all but 2 passed a Kauri reduction of 60 per cent or better."

Came concluded that:

"Kauri reduction values are a somewhat better indication than the accelerated weathering test of the durability of spar varnishes when exposed outdoors."

The significance of the Kauri reduction test in rating the relative durability of varnishes made with some of the newer synthetic resins is in question. In some cases the durability may be decreased with increase in length in oil and increase in the Kauri reduction value.

Turkington and his associates¹⁶ have investigated the properties of phenolic resin varnishes (Bakelite resin BR 254) in the complete range from 100 per cent Chinawood oil to 100 per cent linseed oil, and in oil-lengths from 12.5 gallons to about 75 gallons. They found that with increasing resin content, within the range studied, the BR-254 varnishes show a decrease in Kauri reduction value, but the durability does not decrease in corresponding manner. For many purposes, a 25-gallon varnish may be more serviceable than one of 50-gallon length. All of these vehicles, however, are of superior durability.

Composition of Varnish Vehicles.

While it is possible to give typical formulas for vehicles for aluminum paint, it is not feasible to give all of the directions necessary for the production of satisfactory vehicles. There are many details of the varnish-maker's art, of which an intimate knowledge is necessary before the best varnishes can be made, and in giving typical formulas these are only offered as suggestions which the varnish-maker can employ as a starting point for his vehicle development and to give the general reader an approximate idea of varnish compositions. The exact formula and conditions of processing can be worked out in the light of the varnish-maker's general knowledge and experience.

For many purposes, a vehicle for aluminum paint is desired which gives a durable, hard-drying and tough film. Such a vehicle has general application on metal work outdoors, and the physical requirements of such a vehicle are given in the specification in the appendix. The following formula is for a 50-gallon varnish of this type, which will have a non-volatile content of more than 50 per cent, and readily pass a 60 per cent Kauri reduction test:

Typical Formula for Long Oil Varnish Vehicle for Aluminum Paint

Ester gum	100 pounds
Tung oil	40 gallons
Linseed oil	10 "
Cobalt and lead drier	
Mineral spirits	60 gallons

No figures are given for the amount of drier to be added, since this will vary somewhat with the conditions of manufacture, the particular types of drier employed, and the application of the paint. When mixed with aluminum bronze powder, the paint should set to touch in 2 to 6 hours and dry hard in 24 hours. In vehicles which are to be used for the production of ready-mixed aluminum paint, it is found desirable to keep the amount of lead drier employed at a minimum, or in some cases it is dispensed with entirely.

Very satisfactory vehicles can be made using approximately the same formula but employing other types of synthetic resins, such as the resins made by polymerization of coumarone and indene found in coal-

tar naphtha. These are neutral and unsaponifiable resins. A similar varnish, employing Cumar resin (paracoumarone-indene), has been described by Kenny.⁹ A varnish of this character, made with 34 gallons of Chinawood oil and 6 gallons of linseed oil to 100 pounds of cumar, has given satisfactory service in aluminum paint made with it. Nevindene resin, also made by polymerization of coumarone and indene, likewise gives good results for the formation of long oil varnishes for aluminum paint.¹⁰

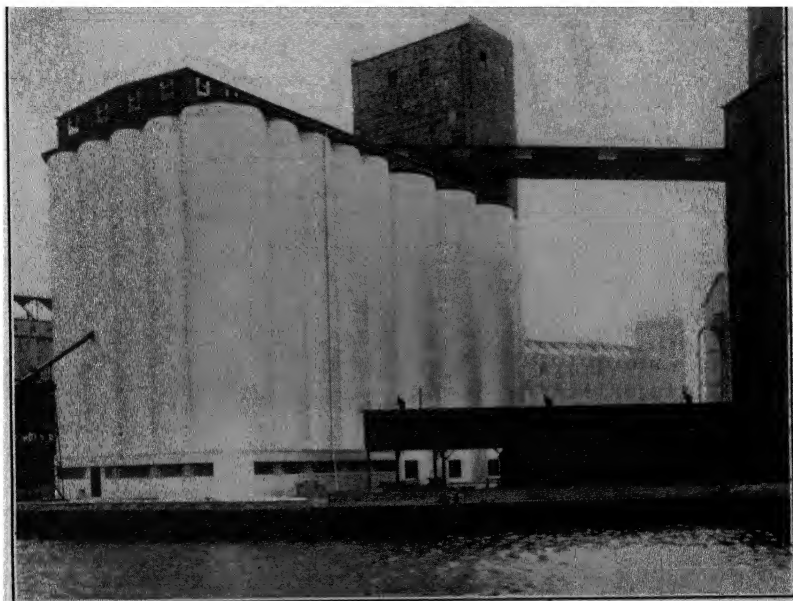


FIGURE 17. Concrete elevator finished with aluminum paint made with phenolic resin varnish vehicle.

The varnishes described above are hardly distensible or elastic enough to be satisfactory for use in aluminum paint to be applied on *wood* outdoors. For this purpose a very long oil varnish, such as an 80-gallon varnish, passing a 100 per cent Kauri reduction test, has proven satisfactory. A typical varnish of this character is given in the following tabulation:

Typical Formula for Very Long Oil Varnish
for Aluminum Paint

Ester gum	100 pounds
Linseed oil	60 gallons
Tung oil	20 "
Cobalt and lead drier.....	
Mineral spirits	70 gallons

In developing this formula, as well as the previous one, the character and amount of drier should be determined by experience. For the mill priming of lumber with aluminum paint, certain special requirements may be placed upon the vehicle which would require modification of this type formula. For example, where rapid drying is essential, it may be desirable to change the relative proportions of the two oils to 50 gallons of linseed oil and 30 gallons of tung oil. Other suitable resins can, of course, be used in place of ester gum.

Coming to the phenolic resins, a great variety of combinations have been tried and found satisfactory, including for example some of the Bakelite, Beckacite, Amberol, Durez, Durite and Phenac resins. An approximately 50-gallon varnish passing a 140 per cent Kauri reduction test and drying in 5 hours can be made with Bakelite oil-soluble resin BR-254.¹ The following formula is recommended by the makers:

Tung oil	200 pounds
Bakelite BR-254	59 "
Mineral spirits	160 "
Liquid Cobalt drier	

The amount of drier may be varied to give the desired speed of drying, but usually about 1 ounce of Liquid Cobalt drier to a gallon of varnish is sufficient. Excess amounts of drier should be avoided in order to minimize skinning. This vehicle is sufficiently elastic or distensible to be used in aluminum paint on wood. The Bakelite resin BR-820 can be used in place of BR-254; it is a darker but lower cost resin of equal durability. Other phenolic resins can be satisfactorily employed, and some of the shorter oil formulations have shown excellent durability. (See also Table 4, page 57). An excellent survey of the properties of certain phenolic resin varnishes over a wide range of oil and resin concentrations has been published by Turkington, Moore, Butler and Shuey.¹⁶

Amberol 226 is a modified phenolic resin which has given satisfactory results in aluminum paint vehicles. A formula recommended by the manufacturers is as follows:

100 pounds	Amberol 226
42 gallons	Chinawood oil
8 "	Medium bodied linseed oil
60 "	Mineral thinner
10 "	Solvent naphtha
1 gallon	Liquid Cobalt drier (2 oz. metal per gallon)

Some results of exposure tests on Amberol varnishes are shown in Table 4.

Coming to the alkyd products, a great variety of resins is again available. They vary from straight alkyd resins to resins modified with oil, phenolic resins, etc. They may be hard, brittle resins or

viscous liquids, incompatible with drying oils or miscible therewith; they are frequently supplied in solution form. Some of these liquid resins and their solutions dry by oxidation to tough films and are said to be of the oxidizing or drying type. Resins produced from glycerine and phthalic anhydride were introduced under the trade name—Glyptal.¹⁸

Dulux vehicle is an oil-modified, glycerol-phthalate resin mixed with suitable thinner, which is available for making aluminum paint. In some grades of Dulux vehicle, aluminum bronze powder leaves freely,

TABLE 4.

EFFECT OF RESIN AND LENGTH IN OIL UPON DURABILITY OF VARNISHES.
New York Paint and Varnish Production Club.

Panels exposed at 45° south in Brooklyn, New York, beginning August 1st, 1931. Flat grain maple panels given 3 brush coats of varnish; steel panels given primer of carbon-black enamel baked on, followed by two coats of varnish as indicated.

Varnish	Per cent Kauri Reduction Passed	WOOD PANELS		STEEL PANELS	
		Initial Failure Weeks	Final Failure Weeks	Initial Failure Weeks	Final Failure Weeks
25-gallon Rosin	16	6	20	5	20
50- " "	99	19	42	15	34
75- " "	138	24	60	24	60
25- " Ester Gum	37	9	34	8	27
50- " " "	107	19	60	15	42
75- " " "	147	28	**	28	**
25- " Amberol F7	82	10	34	10	28
50- " " "	134	24	60	24	60
75- " " "	156	28	60	28	60
25- " Amberol 226	85	12	..	11	42
50- " " "	172	26	50	26	60
75- " " "	210	56	60	41	..
*25- " Bakelite 254	90	**	..	**	..
50- " " "	188	19	..	15	..
75- " " "	219	18	..	15	..
Rezyl 1-G	103	..	..	..	..
" 2-G	90	..	..	..	..
" 3-G	60	..	..	..	..
" 4-G	28	41	60	24	..
" 5-G	32	56	60	24	..

* 40 weeks, both wood and steel panels quite dull and spotted; no visible defects; 80X magnification shows fine uniform interlacing checking. Duplicate wood panels from Nos. 2 and 3 and steel panel No. 3 exposures at same date show negative under 80X magnification.

** Blank spaces indicate exposure test incomplete at date of publication.

while in others it is non-leaving. These vehicles are not miscible with drying oils or varnishes of the ordinary type. They are characterized by marked resistance to aging when exposed to sunlight and weather and make paints of excellent durability.

There is still another group of alkyd resins known as Rezyls. Some of these Rezyls are compatible with drying oils and many varnishes,

and have been satisfactorily used in the production of aluminum paint vehicles. Their general properties have been described by John McE. Sanderson.¹⁵ Another group of alkyd resins is furnished under the trademark "Beckosol." In various combinations these resins can be formulated to produce satisfactory vehicles for aluminum paint. A general description of their properties and some suggestions regarding

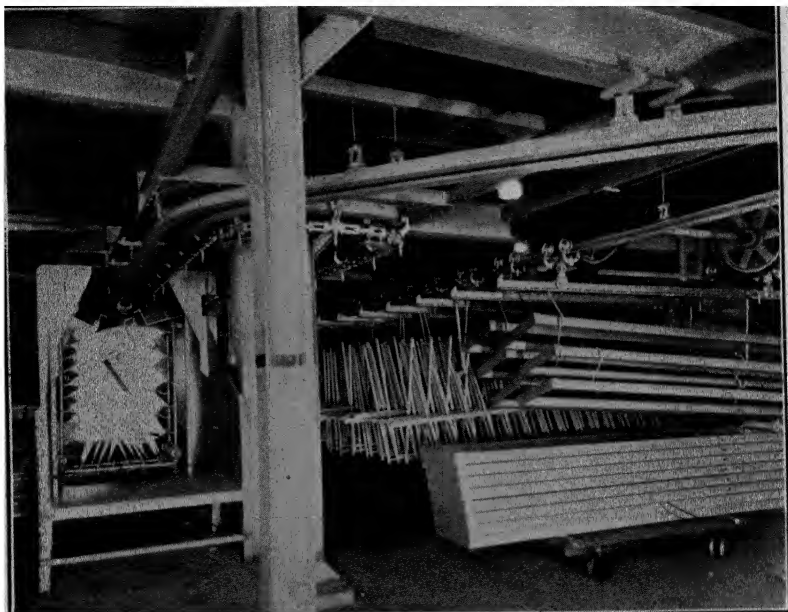


FIGURE 18. Steel frames being coated with aluminum paint by passage between a group of spray guns. (Courtesy of Western Electric Company.)

their use in aluminum paint have been published by W. H. Breuer.² Duraplex⁵ and Esterol¹⁴ are still other alkyd type resins which can be successfully used in vehicles for aluminum paint.

Durability of Varnishes.

While the generalization has been stated that with oleo-resinous varnishes of the conventional type, the durability of the varnish increases with the length in oil, it has been noted that this relationship does not always hold for some of the synthetic resin varnishes, where the resin itself is extremely durable. The New York Paint and Varnish Production Club,¹¹ with the cooperation of a number of industrial concerns interested in the production of resins, paints and varnishes, has made a study of the newer type varnishes in relation to the Kauri reduction value of these varnishes. A variety of typical varnishes in 25-,

50-, and 75-gallon lengths, employing different resins, were secured. These varnishes applied over both wood and steel, were exposed at Miami and Hialeah, Fla., Washington, D. C., Brooklyn, N. Y., and Madison, Wis. Table 4 has been compiled from the test data given in this paper, based on the exposures at Brooklyn, N. Y. These data are of particular interest as showing how widely durability will vary with composition. The varnish films were unpigmented, and the data give no indication of the durability which might be expected from these varnishes when pigmented with aluminum bronze powder. These data show that, "in the older type varnishes where the resins had only slight durability, the addition of oil up to certain limits produced varnishes increasing in durability as the amount of oil was increased. Here the Kauri reduction test seemed to indicate the durability with fair accuracy as it measured the distensibility which is apparently the determining factor." There was some question raised as to whether lack of miscibility of the Kauri solution with some of the vehicles did not introduce a disturbing factor into the test. The fact was brought out, however, that increase in length of oil of some of the synthetic resin varnishes does not necessarily mean an increase in durability. All of these varnishes would exhibit greatly increased durability if pigmented with aluminum powder.

Miscellaneous Vehicles.

Another group of vehicles used for aluminum paint is commonly known as bronzing liquids. The term has no technical significance except as it has been applied to a variety of liquids used with aluminum powder for decorating radiators, picture frames, fixtures, and the like. A commonly used vehicle of this type is the so-called "gloss oil." Some manufacturers, however, apply the term bronzing liquid to high-grade long oil varnishes.

Gloss oils are solutions of treated rosin or other resin in mineral spirits, and even the best contain only a small amount of the drying oils such as linseed or tung oil. They dry rapidly—usually in less than one hour—and possess little toughness and durability. They are, however, cheap and for many purposes make a satisfactory vehicle for aluminum paint, particularly where durability is relatively unimportant. Although their lack of weather resistance is the chief drawback to their use, nevertheless the protective effect of aluminum powder is so marked that they give fair service on metal surfaces outdoors. Aluminum paint made with a gloss oil may give good protection in two-coat work on metal for a period of a couple of years under conditions where a good long oil varnish vehicle with aluminum powder will last 6 or 7 years.

Vehicles containing treated fish oils have been used with some success in aluminum paint, particularly for application on surfaces which are

to be heated. Some of these vehicles are slow drying, however, and hence tend to collect dirt very badly.

Spirit varnishes, of which a solution of shellac in alcohol is an example, may also be used with aluminum powder. They are likewise lacking in toughness and should only be employed where this feature is not a drawback. The alcohol used with shellac will contain water

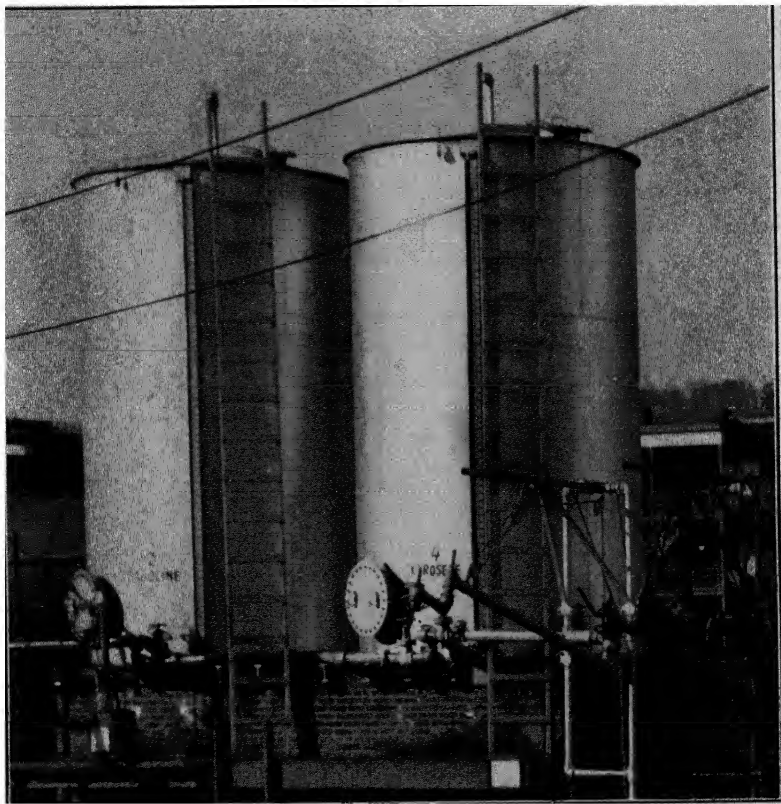


FIGURE 19. Oil storage tanks protected with aluminum paint, at West Orange, New Jersey.

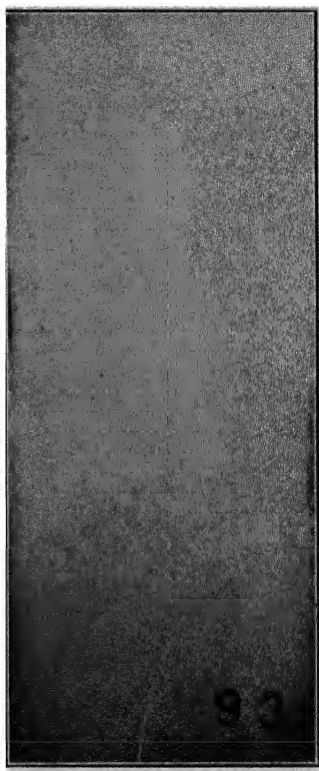
and will react with aluminum powder on continued standing. Because of the gas generated, such a paint should not be confined in an air-tight container.

The well known and fragrant "banana oil" bronzing liquid is a type now infrequently used except for decorative purposes. It consists of a solution of nitrocellulose in amyl acetate. It has little to recommend it except its property of rapid drying.

Pyroxylin Lacquers.

The early tests gave rather poor exposure results for mixtures of cellulose nitrate lacquer and aluminum powder. Since that time, however, revolutionary changes have been made in the lacquer industry as the result of the development of the so-called "low viscosity" cellulose nitrate. The early cellulose nitrate or pyroxylin lacquers were limited in composition, because not more than about 6 ounces of pyroxylin could

FIGURE 20. Steel test panel showing durability of lacquer pigmented with aluminum powder; two and three coats after $6\frac{1}{2}$ years' exposure at New Kensington.



be dissolved in a gallon of lacquer and still leave the lacquer thin enough in consistency for satisfactory application. By changing the degree of nitration and the character of the solvent employed, the modern low-viscosity lacquers carrying as much as 16 ounces of pyroxylin per gallon have been developed. These lacquers naturally give a very much thicker and more durable film on drying. In addition to the true solvents employed in these lacquers, there are employed non-solvent thinners which beneficially modify the fluidity, rate of drying, etc. There are also added various materials called plasticizers, which increase the toughness of the lacquer film, and gums and resins which increase its

adhesion and luster. The most durable lacquers for outside service generally contain synthetic resins of the phenolic or alkyd type. These lacquers, mixed with various colored pigments, have been extensively employed in automobile and furniture finishing and other places where a quick-drying film of good wearing qualities and attractive appearance is desired.

Aluminum powder can be very successfully applied in pyroxylin lacquers and the mixture gives the usual quick-drying lacquer film. Aluminum powder usually does not leaf in pyroxylin lacquer, but gives a film of somewhat frosted appearance with good light-diffusing characteristics. In common with other pigments, less aluminum powder can be incorporated in these lacquers than in oil-base paints; the proper amount may vary from about 8 to 16 ounces per gallon of lacquer. The customary method of applying pyroxylin lacquers is by spraying. In applying lacquers, care should be taken to use only the special thinner supplied or recommended by the manufacturer for mixing with his lacquer.

The durability of lacquer films with outdoor exposure, sunshine and rain, is greatly increased by the addition of aluminum powder. Sunlight is one of the important factors in the deterioration of lacquer films, and the protection given by the metallic aluminum flakes is both obvious and valuable. To illustrate this point, mention may be made of a steel test panel given 2 and 3 coats of a pyroxylin lacquer mixed with aluminum powder in the proportion of 2 pounds per gallon. The mixture was so thick that it was brushed out with difficulty and would have been impractical for general use. The panel was still in excellent condition, however, after 8 years' exposure in New Kensington at an angle of 45° facing south. Another lacquer with 1 pound of aluminum powder per gallon, applied on bare steel in 3 coats by spraying, was still in good condition after 7 years.

Other Lacquers and Vehicles.

Lacquers made with synthetic resins, such as Bakelite, Glyptal, Rezyl, Vinylite, etc., may also be employed with aluminum powder. The dry, hard coatings are especially useful for resisting softening through attack by agents such as turpentine or gasoline, which injure oil-base paints. Many of them make good baking enamels and are excellent finishes for metal surfaces which are to be heated to relatively high temperatures. Some of them also show good acid resistance. Lacquers made with vinyl resins, such as Vinylite, make excellent vehicles for aluminum paint for special purposes. Such lacquers, when dry, are quite inert and have very good chemical and solvent resistance. Properly formulated, they show good durability on outdoor exposure.

Bituminous Paints.

Still another class of vehicles finding employment in aluminum paint is made from a bituminous base. The bituminous materials used in such paints are quite varied in nature and comprise asphalt, asphaltite, tar, pitch, and the like. Bituminous paints are made by compounding these substances with volatile solvents, and in some cases, vegetable drying oils, resins, fillers and pigments are added. One of their important characteristics is high moisture-resistance or waterproofing power.

In some bituminous paints aluminum powder will leaf freely and to such an extent as to give the paint film a brilliant metallic aluminum surface without any apparent trace of the black bituminous paint in which it is incorporated.⁷ If such a bituminous-aluminum paint is spread on glass, it is interesting to compare the black base, looking through the glass from the back, with the brilliant aluminum leafed surface seen from the top. Some bituminous paints permit little or no leafing of the aluminum bronze powder; in general, it may be said that those employing a coal-tar solvent such as toluol or xylol, leaf the best. One other condition for ready leafing is that the mixture shall be thin enough in consistency to permit the free movement of the aluminum flakes in the "wet" paint film. The leafing power usually diminishes on standing in the mixed paint, so that such paints must be mixed and used as needed. Aluminum powder leafs poorly, if at all, in emulsified asphalts of the types so far developed.

Exposure tests show that aluminum powder lends to bituminous paints marked protection against sunlight. While it will not in some cases entirely prevent checking or alligating of the paint film, it reduces the extent and seriousness of such defects, and adds materially to the life of the paint film. In cases where it is desired to have a priming coat of bituminous paint next to a metal surface, it can be pigmented with aluminum, or a top coat of oil-base (spar varnish) aluminum paint can be applied over the bituminous paint without bleeding through of the black base.

Powder Content of Paint. ✓

The most generally satisfactory amount of Standard Varnish powder has been found to be about two pounds of powder per gallon of oil or varnish. This is in striking contrast to the lead pigments, for example, which are employed in amounts up to about 30 pounds per gallon of oil. A typical varnish, such as used for aluminum paint, will weigh about 7.3 pounds to the gallon. Aluminum powder, Standard Varnish grade, has a bulking value of about 0.05 gallon per pound of powder, so that two pounds of powder with a gallon of vehicle will make approximately 1.1 gallons of mixed paint. Slightly higher bulking values are shown by the Lining grade of powder. A simple calculation also shows that the pigment portion—aluminum powder—constitutes

about 21 per cent, by weight, of the paint. Aluminum powder can be used up to 30 per cent, particularly if a vehicle of rather thin consistency is mixed with it. However, the addition of much more than this amount generally interferes with proper brushing of the paint, and the paint may likewise prove slightly less durable.

When a powder of Lining grade fineness is employed, something less than two pounds of the powder per gallon of vehicle can be employed without loss in durability as compared with a paint made with 2 pounds of "Standard Varnish." One and one-half to one and three-quarter pounds of Lining powder are frequently used under these conditions.

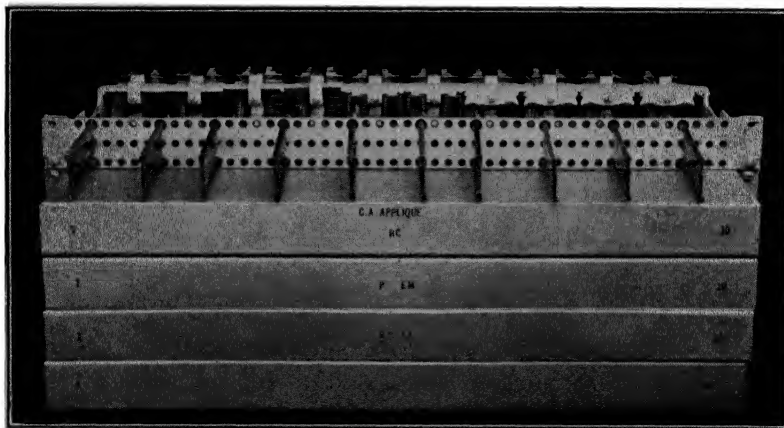


FIGURE 21. Relay rack unit assembly for telephone exchange; aluminum paint finish baked after application. (Courtesy Bell Telephone Laboratories.)

Two pounds of paste (65 per cent aluminum) per gallon of vehicle is a proportion commonly used, although an amount of two and one-half pounds of paste per gallon may be used where severe exposure conditions are to be met.

Under certain circumstances, as for example, where aluminum paint is applied over porous concrete, plaster, open-grained or badly weathered wood, it may be necessary to reduce the powder content to compensate for the excessive amounts of vehicle absorbed through the surface.

The pyroxylin lacquers can only be mixed with about 8 to 18 ounces of fine mesh powder per gallon if the proper spraying consistency is to be preserved. Where durability is important, the number of coats of pigmented lacquer can be correspondingly increased.

Grade of Paste or Powder.

The grade or fineness of powder employed in formulating aluminum paint will depend on the appearance and service desired. For general outdoor painting purposes, the grade known as "Standard Varnish" has

been widely employed and has established a standard of appearance and performance for aluminum paint. "Extra Brilliant" powder contains a higher percentage of large flakes and gives a somewhat brighter appearing paint film. The actual difference in reflectivity of aluminum paint made with Extra Brilliant powder, as compared with Standard Varnish, is only two or three per cent, but it may be distinctly noticeable to the eye. The surface of the paint made with Extra Fine Varnish powder, however, gives a smoother appearing paint film.

Of recent years, the trend has been towards the use of finer grades of powder in order to secure a smoother appearing paint film. There is an economic question involved also, since the finer grades are in general more expensive. However, with smaller, thinner flakes, and more flakes per pound, less powder need be employed to give the required durability in terms of Standard Varnish powder. The "Standard Lining" grade has therefore been used in increasing quantity.

In line with this trend has been the development of aluminum powder in paste form. The successful paste has contained powder of Lining fineness and makes a smooth, bright paint film. It has advantages in handling and performance which indicate a large increase in its use.¹⁸ The content of mineral spirits (usually 30 to 40 per cent) must be taken into account in formulating aluminum paint, both from the standpoint of compatibility and composition. The bulking value of powder in paste form is influenced both by the fine Lining powder of which it is composed, and by its liquid content; hence it is materially higher than that of the dry powder. One sample with 65 per cent metal content was determined experimentally to have a bulking value of 0.082 gallon per pound.

Mixing Aluminum Paint. ✓

The most convenient system of mixing aluminum paint is to weigh out the required amount of powder and place it in the bottom of the mixing container. If the aluminum paint is purchased in a double compartment container, just the right amount of pigment will be packed in the one compartment for mixing with the vehicle in the other. A portion of the measured volume of vehicle is then poured over the powder and the mixture stirred with a wooden paddle until the powder is completely wetted by the liquid. The remainder of the vehicle is then poured into the container and the whole stirred to a uniform consistency. A comparative test showed that it required only two or three minutes to measure out the ingredients and mix a gallon of aluminum paint in this way. Mixing should be accomplished with a minimum of stirring, since excessive stirring will injure the leafing characteristics of the aluminum flakes. Mixing by mechanical stirring should therefore be carefully conducted so as to avoid unnecessary agitation of the paint.

If aluminum paste is used as the pigment, it can be mixed with the vehicle, much as any other paste pigment is mixed. It has the advantage over aluminum powder that there are no loose flakes to fly around. To obtain the best results with aluminum paste it is essential that the correct mixing procedure be employed.

In all cases the vehicle should be added to the paste and not the paste to the vehicle. The paste should be placed in the bottom of a container and not more than 5 per cent of the total amount of vehicle poured over it. This vehicle should be incorporated with the paste before an additional like amount is added and thoroughly mixed. This

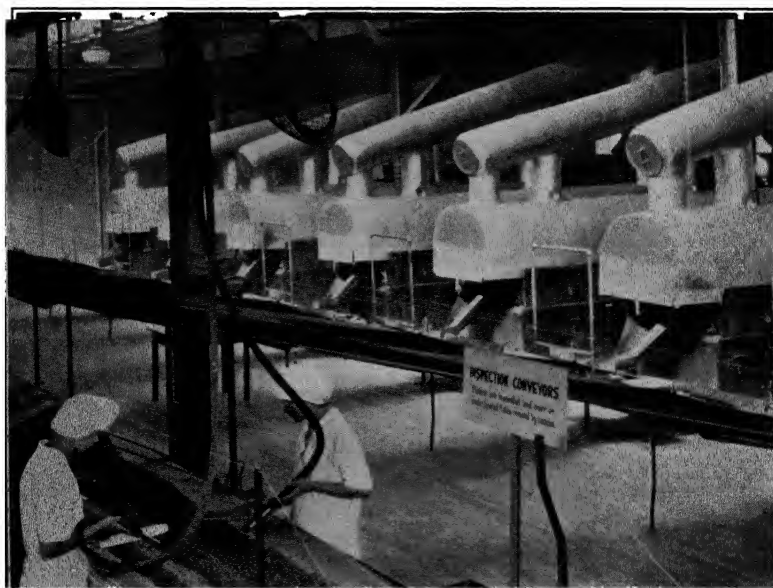


FIGURE 22. Aluminum-painted toasting ovens in the Rice Flake Department of H. J. Heinz Company, Pittsburgh.

procedure is followed until the paste is thinned sufficiently to flow readily in the can. Then the remaining portion of vehicle (usually about half the total) is poured in and mixed at one time. By adding small portions of vehicle with thorough incorporation, the paste will be better wet by the liquid and mixing can be accomplished in a much shorter time, with complete absence of agglomerates of paste. Where a large amount of paste is to be mixed, it has been found advantageous to pour a small portion of the vehicle over the paste and stir it to a uniform mixture by means of a mechanical mixer of the portable type. The rest of the vehicle is then added and the mixing finished by stirring with a large paddle.

Ready-Mixed Aluminum Paint. ✓

The making of a good ready-mixed aluminum paint involves a number of difficulties. The loss of leafing of aluminum powder on standing in a vehicle can be controlled to a certain extent by selection of a suitable vehicle composition. Some aluminum paints will show substantial leafing power even after standing six months or more, while others will lose all tendency to leaf within a few days of mixing. In most cases, at least, it is advantageous to use a vehicle of low acid number. Lead drier should be avoided. Thinners of high surface tension, such as toluol and the like, are used in some successful ready-mixed paints to promote leafing.

Some vehicles have a darkening effect upon the powder if allowed to stand in contact with it for an extended period. This is obviously undesirable. Tests have shown that water in a vehicle will slowly

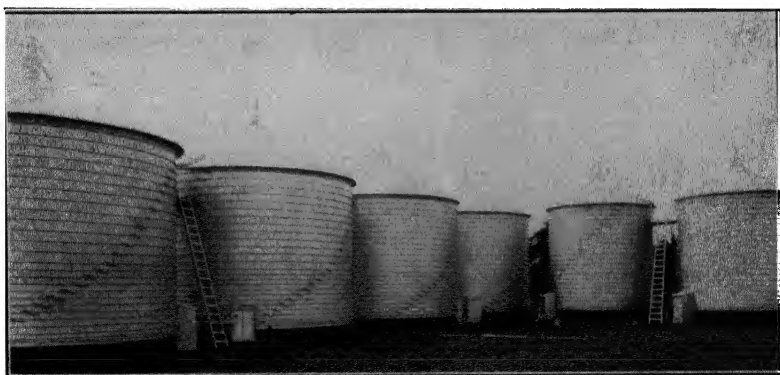


FIGURE 23. Vinegar tanks of wood, coated with aluminum paint.

liberate hydrogen on standing in contact with aluminum powder. Cans in which paste, powder or paint are to be packed should be dry. Bringing open cans out of a cold storeroom into a warm room may cause moisture condensation on the inside surface with subsequent damage to the paint. The difficulty of gas generation, while occasionally met with, has not been a serious one in the development of ready-mixed paints, since it can be readily avoided by taking the proper precautions.

Under some conditions of use, loss of leafing power is not an important consideration if the color of the paint has not likewise depreciated. Leafing adds appreciably to the opacity and hiding power of aluminum paint, so that more coats might be required with a non-leafing paint. The best test is in practical application, and a ready-mixed paint should be examined to determine whether it has the proper spreading, covering and hiding properties, and whether the color and appearance are likewise satisfactory. Of course, the vehicle should be a durable one, especially if the paint is to withstand weathering.

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Chapter 5.

Aluminum Paint in the Protection of Metals

Aluminum paint has proved its merits in service as a protective coating for metals. Originally used on iron and steel, its application has been extended to the coating of aluminum, magnesium, galvanized iron and other metals. In the protection of metals its principal value lies in providing a tough, protecting coat of long life and high resistance to moisture penetration. Other properties, however, have special significance in connection with certain applications. While behavior in service is the ultimate criterion of paint performance, the results of numerous tests under controlled conditions are significant in appraising the value of aluminum paint and placing it with respect to other paints which may have been in use for a longer period.

Early Tests.

Probably the first extensive test of aluminum paint to be made in this country was carried out at the Institute of Paint and Varnish Research in Washington under the direction of H. A. Gardner. Some 58 panels coated with aluminum paint in one or more coats, and six comparison panels with red lead, blue lead, zinc powder, etc., were exposed at Washington in October, 1920. In fact, a couple of panels with aluminum paint were exposed at Atlantic City in May, 1919, and it was the promising behavior of this earlier test that inspired the second more comprehensive test begun in 1920. Circulars Nos. 130, 153, 187, and 231 of the Paint and Varnish Manufacturers' Association give the results of inspection of these panels after exposure for intervals of 9, 19, 31 and 52 months.¹⁰

Aluminum paint gave a very satisfactory service as primer or as top coats over other primers. After 52 months' exposure at Washington, one coat of red lead or blue lead as primer with one top coat of aluminum paint was in "very good to excellent condition" and two top coats of aluminum paint were reported as in "excellent condition" and "very good condition." As a protective coating for steel, the aluminum paint gave a good account of itself.

The National Bureau of Standards, in 1920, also started a series of tests of aluminum paint coatings on steel. Walker and Hickson,¹⁷ reporting on these tests after 3½ years' exposure, found that aluminum paint, properly formulated, was a durable protective coat for steel.

American Railway Association.

A committee of the Equipment Painting Section, Mechanical Division of the American Railway Association, tested the merits of aluminum paint on both steel and wood. Their 1930 report (Circular E. P. S. 112) describes this test as follows:²

"The test consists of forty-five steel panels making a series of fifteen, of three panels each, with the various recommended mixing vehicles with three different grades of aluminum bronze powder known as: Extra Fine Powder, Standard Powder, and Extra Brilliant Powder. There are also twenty-four wooden panels in this group, making eight series of three panels each with the various recommended vehicles and different grades of powder.

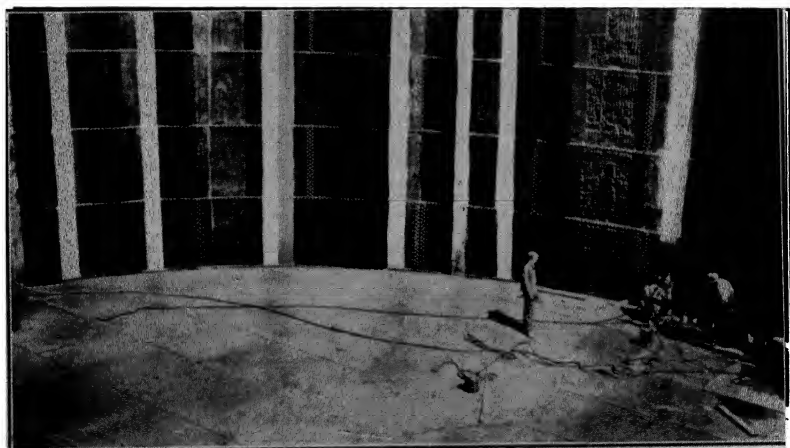


FIGURE 24. Interior of million-gallon water tank at Ambridge, Pa., showing application of paints on different test sections. (Courtesy of Bakelite Corporation.)

In this group also will be found a series of three panels using recognized primers with two top coats of the three different grades of aluminum powder, and a series of three using aluminum paint as a prime coat with various top coats of oil paints.

The test on steel and wood consists of the aluminum bronze powder mixed with the various vehicles in the proportions of two pounds of powder to the gallon of vehicle. Each vehicle was mixed with the three different grades of powder and painted on three panels."

The details of this test are quite difficult to summarize, but it is sufficient to quote the conclusions of the committee referring to the aluminum painted panels:—

"After thirty-eight months' exposure, all but one manufactured vehicle (pigmented with aluminum powder—Author) shows splendid results as a protective coating for both steel and wood where two or more coats are applied."

Ambridge Tank Test.

With the cooperation of the borough of Ambridge, Pennsylvania, and the Pittsburgh-Des Moines Steel Company, a very extensive series of tests was carried out to determine the suitability of paints for protecting steel water tanks.¹² In this test 198 panels, each 16 inches wide and 24 feet high, were painted on the interior of the tank, each panel being protected with a different commercial coating. (See Fig. 24). The water tank had been kept in service for a period of 571 days when the final inspection was made. Several intermediate inspections were made, at which times the tank was drained for short intervals and then refilled. A summary of the results of this test is given in Table 5; 148 of the 198 panels included in the test have been classified into 14

TABLE 5.

FINAL REPORT OF AMBRIDGE TEST OF PAINTS FOR WATER TANK INTERIORS.
Technical Bulletin No. 3304—Pittsburgh-Des Moines Steel Co.

Classification	Average Rating for Class	Number in Class	Highest Rating Any Panel	Lowest Rating Any Panel
			Per cent	Per cent
Hot Bituminous Coatings	68.9	8	85	35
Aluminum Paints*	67.1	17	92	0
Asphalt Emulsions (plain)	64.7	3	82	50
Red Lead and Linseed Oil Paints..	64.5	10	85	30
Coal Tar Paints.....	57.8	13	85	12
Thick Plastic Coatings	49.0	4	67	32
Asphalt Emulsion and Filler.....	47.3	3	75	32
Elaterite Coatings	46.5	6	67	5
Misc. Cold Bituminous Paints....	44.0	20	75	0
Synthetic Gum Vehicle Paints*....	37.9	44	100	0
Miscellaneous Linseed Oil Paints..	34.5	14	82	0
Clear Varnish Finishes.....	31.1	9	45	10
Gilsonite Asphalt Paints.....	30.5	4	60	0
Pyroxylin Base Paints.....	25.0	2	50	0

* Nine aluminum synthetic gum vehicle paints have been classified both with the aluminum paints and the synthetic gum vehicle paints.

different types of paint. The aluminum paints received the highest rating of any of the paints in the test, and were only exceeded in their average efficiency by the hot bituminous coatings, which would scarcely be classified as paints. One of the aluminum paints was apparently poorly adapted for this service, but in spite of this low rating, the average of the group was very satisfactory.

Aluminum Research Laboratories' Tests.

Just a little more than 15 years ago, the research group of Aluminum Company of America decided that there was a much wider field of usefulness for aluminum powder and aluminum paint if only the necessary technical information could be obtained and made available. To reach this objective, a research program was started which has continued to this day. In no small measure, the results of these investigations have made possible the present volume. Throughout the major portion of

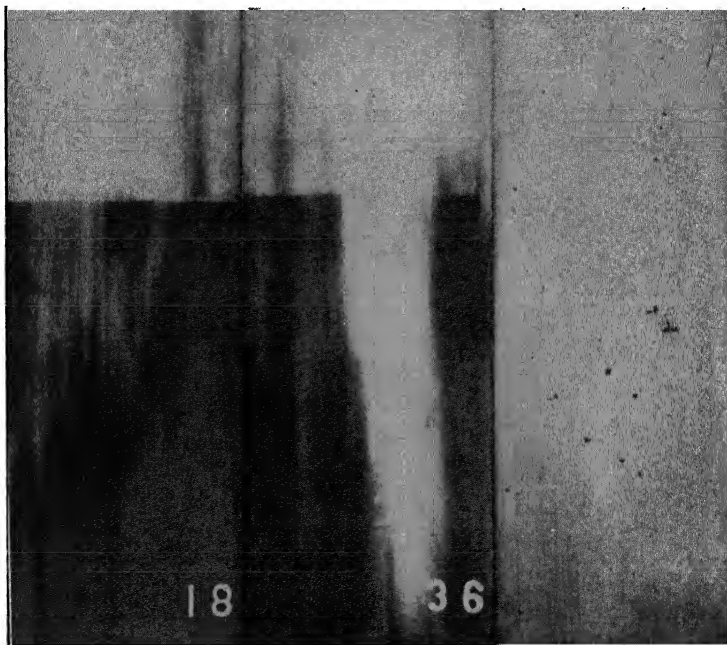


FIGURE 25. Aluminum paint on test panels (2 coats below, 3 coats above) after 12 years' exposure at New Kensington at an angle of 45° facing south. Panels Nos. 18 and 36 are steel and No. 47 is galvanized iron.

this period, these investigations have been in charge of Robert I. Wray, one of the pioneer workers in this field. The interest of other Laboratories and paint manufacturers was soon aroused so that today the paint user in America, and many other countries as well, has available aluminum paint adapted to many applications, and a wealth of evidence as to its performance under innumerable conditions of service.

One of the first questions asked by a prospective user of aluminum paint was—how long will it last and protect steel from rusting? The evidence on these points was admittedly meager in the early '20s.

Reference has already been made in this chapter to these very early tests. The most important object, therefore, of the Aluminum Company of America's early research in this field was to determine the most suitable types of vehicles for aluminum paint and to establish their useful life and protective value. Some of the results with respect to vehicle formulation have been summarized in the previous chapter on the composition of aluminum paint. Some of the data on paint performance will now be presented.

In Fig. 25 are shown two panels of steel coated with aluminum paint, with two coats on the lower part of the panel and three coats on the upper third. The aluminum paint was applied to the clean bare steel—no other primer of any kind was employed. The panels were exposed at New Kensington, Pennsylvania, facing south and at an angle of 45 degrees. This exposure condition was employed in all the tests to be described, and will be understood unless some statement to the contrary is made. At the time the photograph was made, the panels had been exposed continuously for twelve years. On panel No. 18 there is substantial rusting on the two-coat portion of the panel but very little on the upper part protected with three coats. Panel 36 is in about the same condition, except for a streak down the center of the two-coat portion, where protection was still very good. It is probable that in applying the paint a somewhat thicker film was left in this center area. However, even the two-coat areas are in good condition for repainting. While the rusting looks black in contrast with the aluminum paint, the condition there is not serious. The rust formation has stained the aluminum paint without, however, causing any loss of adhesion. There is *no* deep pitting and the rust is not lifting the paint film. The aluminum paint on panel No. 18 was made with a varnish vehicle meeting Federal Specification No. 18, now TT-V-121, (45 per cent non-volatile content, meeting a 50 per cent Kauri reduction test), which had been thinned with 10 per cent mineral spirits. Aluminum powder, Standard Varnish grade, was used in the proportion of 2 pounds per gallon. Panel No. 36 was painted with a proprietary varnish vehicle, commercially available at the time. Panel No. 47, exposed for the same period, was a sheet of galvanized steel to which had been applied two coats of the same aluminum paint used on panel No. 18. Protection was still good and there was no evidence of peeling except at a few very small spots. It is the general experience that paint on vertical surfaces lasts substantially longer than on surfaces exposed to the sun at an angle of 45 degrees to the horizontal. This fact only emphasizes the excellent performance of aluminum paint in these tests. Other examples of extended paint durability will be illustrated on succeeding pages.

One or two examples of extended paint service are of interest for correlation with the panel tests. The Washington Crossing bridge in Pittsburgh is a steel and concrete structure of impressive size and

design. It was finished in 1924 and is probably the first large bridge to be protected with aluminum paint. The steel work was given a shop coat of proprietary composition; the pigment contained among other ingredients, iron oxide and a small percentage of a chromate. A field coat of approximately the same composition was applied and this was followed by two finish coats of aluminum paint in a varnish

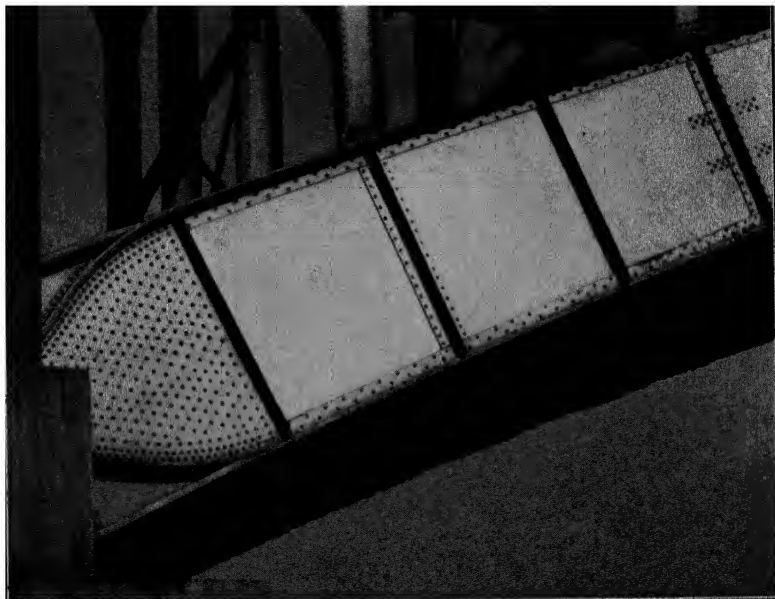


FIGURE 26. Washington Crossing bridge at Pittsburgh, showing excellent condition of aluminum paint; photograph taken after nine years' service; see Figure 15 for general view of bridge.

vehicle. The aluminum paint was satisfactory in every particular and far outlasted the paints which had been previously employed on bridges in the same neighborhood. A photograph of a main bridge member taken nine years after painting is shown in Figure 26.¹⁸ The paint coating was still in good condition at the end of ten years, when it was decided to apply two more coats of aluminum paint. Panel tests of the aluminum paint and competing paints also demonstrated the durability and the superiority of the aluminum paint chosen for the structure. The results of the panel tests were in close agreement with the actual performance of the paints on bridges.

An important factor in the durability and protective value of a paint film is its thickness. Three coats generally give better protection than two. Of course, it is recognized that the second and succeeding coats cover pinholes and other unavoidable defects in the first coat or

coats and tend to give a paint film of more uniform thickness. Data in the next chapter also show that the resistance to penetration by moisture increases directly with the thickness of the film. The factors controlling thickness should therefore be given careful consideration. One of these factors is the consistency of the paint. In Figure 27 are shown 3 steel panels painted with 2 and 3 (on upper third) coats of aluminum paint. The vehicles employed were varnishes of similar characteristics but they differed in viscosity. The "thickest" vehicle was used in the paint on panel No. 194; this vehicle had a viscosity of tube C on the Gardner-Holdt scale. The vehicle in the paint on panel No. 197 had a viscosity of tube A and the most fluid vehicle, that on

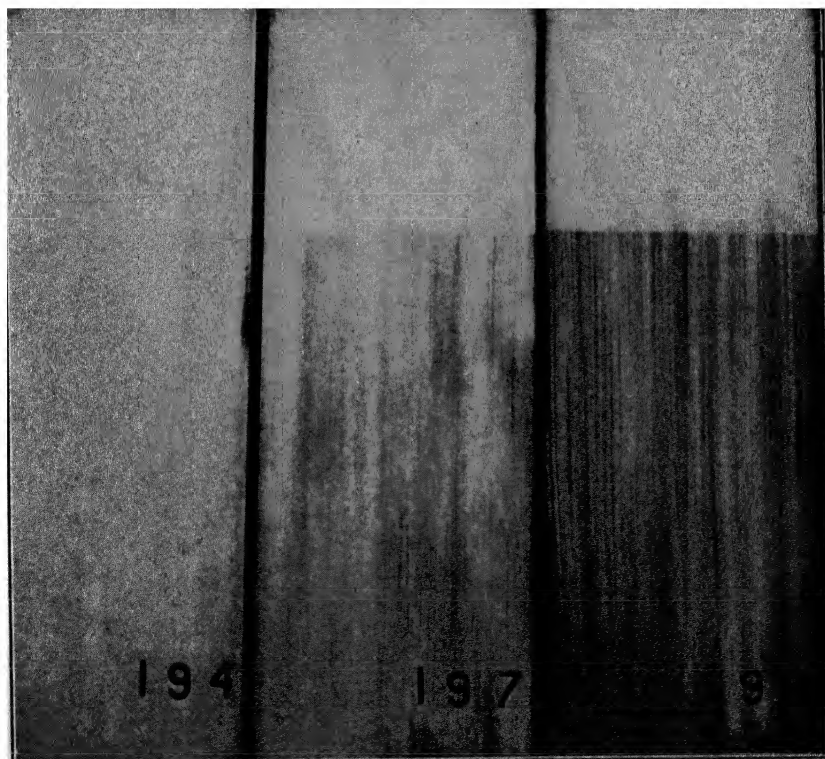


FIGURE 27. Panels showing effect of thickness of paint film upon durability (2 coats below, 3 coats above); thickest paint film is on panel No. 194, and thinner coatings on No. 197 and No. 198.

panel No. 198, had a viscosity of less than tube A (A minus). After three years' exposure the paint on panel No. 194 is still in good condition on both the 2 and 3-coat areas. Failure is beginning on the 2-coat area of No. 197, and is quite pronounced on the panel painted with the

very thin paint (No. 198). The 3-coat areas are all in good condition. Naturally, thinner paint films, offering less protection, were obtained with the vehicles of lower viscosity.

Another factor in the durability of a paint film is the pigment concentration. This is illustrated by the panels of Fig. 28 which were given *only one coat* of aluminum paint in order to show any differences with the shortest possible exposure. The aluminum paints on these panels were made with pigment concentrations of 1.5, 2 and 2.5 pounds

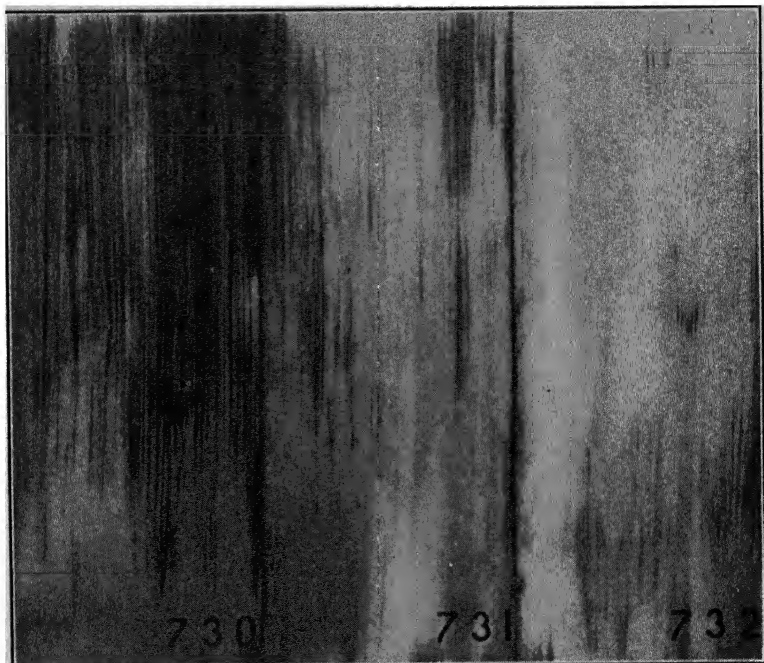


FIGURE 28. Steel panels with one coat of aluminum paint showing how durability increases with increase in pigment concentration; 1.5, 2.0, 2.5 pounds of aluminum paste per gallon of vehicle on panels from left to right.

of aluminum paste (65 per cent metal) per gallon of vehicle in the order given, Nos. 730, 731 and 732. The photograph, made after 15 months exposure, shows the paint films failing in the same order; the highest pigment concentration gave the greatest durability. The amount and degree of staining of the paint film is evidence of the rusting taking place. Here again, however, there is no pitting of the steel and lifting of the paint film.

The fineness of flake (covering area) in a way affects pigment concentration and hence durability. Increased covering area is evidence

of a greater number of flakes per pound and, as far as durability is concerned, has the same qualitative effect as increased pigment concentration. In Fig. 29 are shown two panels with 2 coats (lower) and 3 coats (on upper third) of aluminum paint after 38 months' exposure. Two pounds of powder per gallon was employed in one paint and two pounds of paste in the other. The pigment of panel No. 544 was a

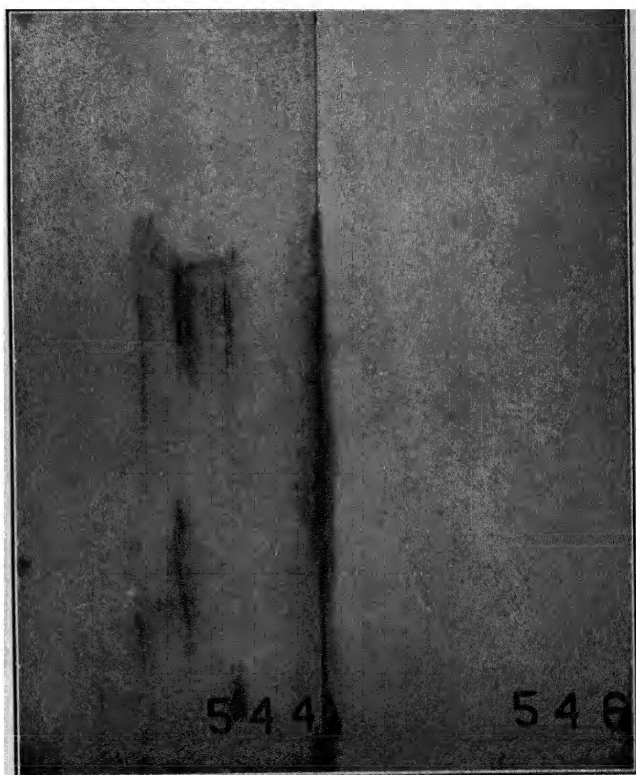


FIGURE 29. Steel panels showing effect of fineness of flake of aluminum powder on durability; Standard Varnish powder on panel No. 544, fine aluminum paste pigment on panel No. 546.

Standard Varnish powder (covering area about 3500 cm.² per gram) and the pigment of panel No. 546 was a paste (covering area about 10,000 cm.² per gram). Comparative conditions were maintained by compensating for the thinning action of the mineral spirits in the paste. A more durable paint film was obtained with the high covering pigment of the paste. The paint film made with paste was also smoother and remained substantially brighter and cleaner than the paint film made with Standard Varnish powder.

In the course of hundreds of exposure tests, sufficient data have been obtained to permit an analysis of the durability of aluminum paints made with vehicles of different characteristics. For this comparison, there were selected 140 panels, coated with 140 different aluminum paints. Each paint was mixed in the proportion of 2 pounds of Standard Varnish aluminum powder per gallon of vehicle. The vehicles varied widely in their characteristics. However, no synthetic resin vehicles of the phenolic or alkyd type are included in this comparison. As a standard of performance, they were divided into two groups. The vehicles in one group had a non-volatile content of 50 per cent or more, a viscosity of tubes A to D, passed a Kauri reduction test of 60

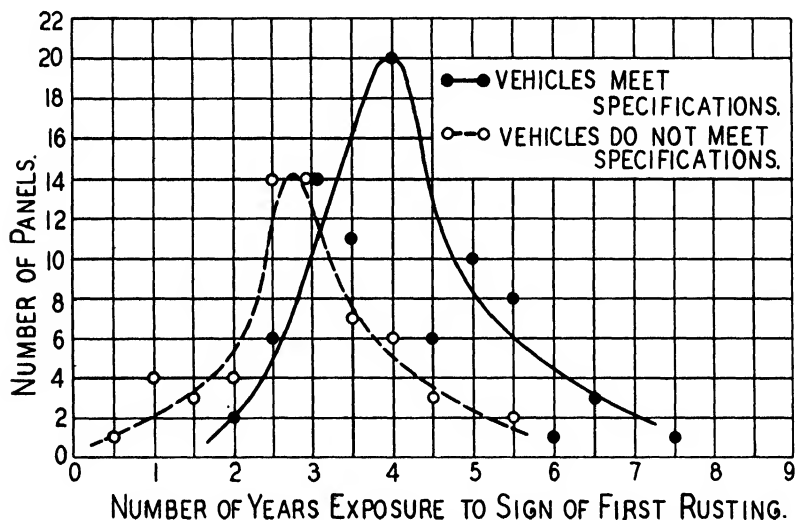


FIGURE 30. Durability of 2 coats of aluminum paints made with vehicles meeting long oil varnish specification in comparison with those not meeting specification.

per cent, and made an aluminum paint with suitable leafing, spreading and drying characteristics. The vehicles in the second group failed to meet these requirements in one or more particulars. These paints were all applied in 2 and 3 coats over bare steel panels. The tests were not all started at one time, but have been exposed at various times over a period of 11 years. The results of these tests are shown in Fig. 30, where the time in years' exposure, before the first signs of rusting appeared on the 2-coat areas is plotted as one ordinate and the number of panels of this age and condition as the other. The result is a pair of typical frequency curves. Comparison of the peaks indicates that, on the average, an aluminum paint made from a varnish vehicle meeting the requirements outlined, will give about $1\frac{1}{2}$ years more service

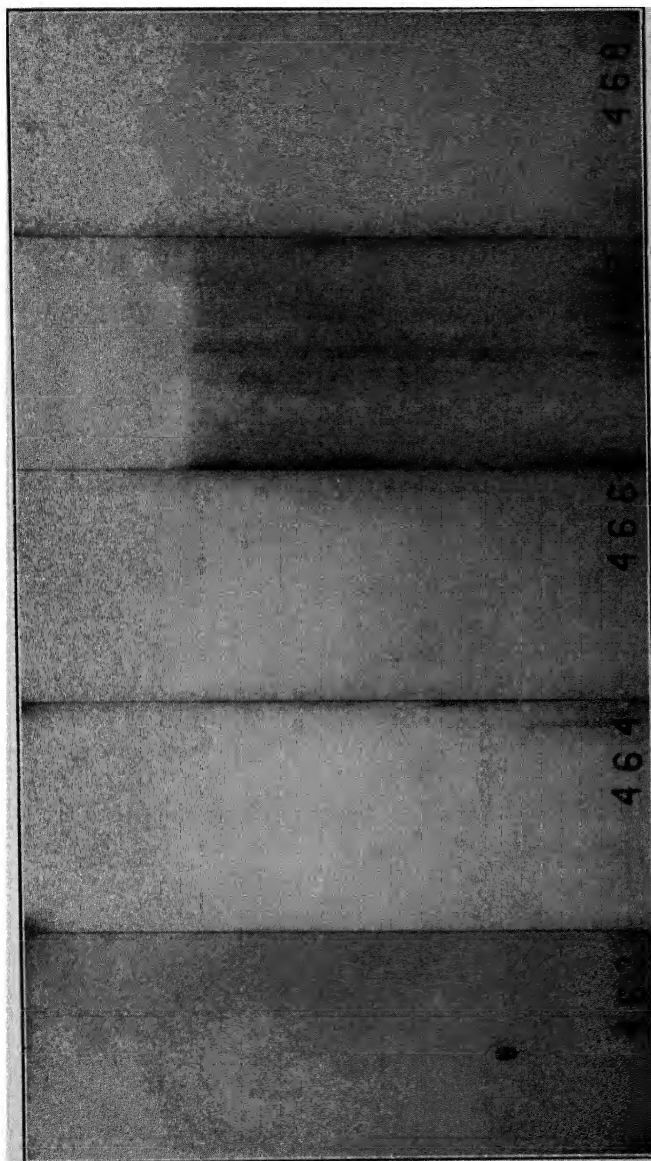


FIGURE 31. Durability on steel of aluminum paint made with different types of vehicle resin; from left to right—alkyd resin, Bakelite resin, Amberol resin, ester gum resin and coumarone resin varnishes.

under these conditions than one not meeting these requirements. Most of the vehicles not meeting the specified characteristics, but giving satisfactory life, were either of rather high viscosity or had a very high non-volatile content. In other words, they were of a type to give thick paint films, which would account for their durability.

Mention was made in the previous paragraph, that the vehicles compared in Fig. 30 included none of the phenolic or alkyd resin type. The

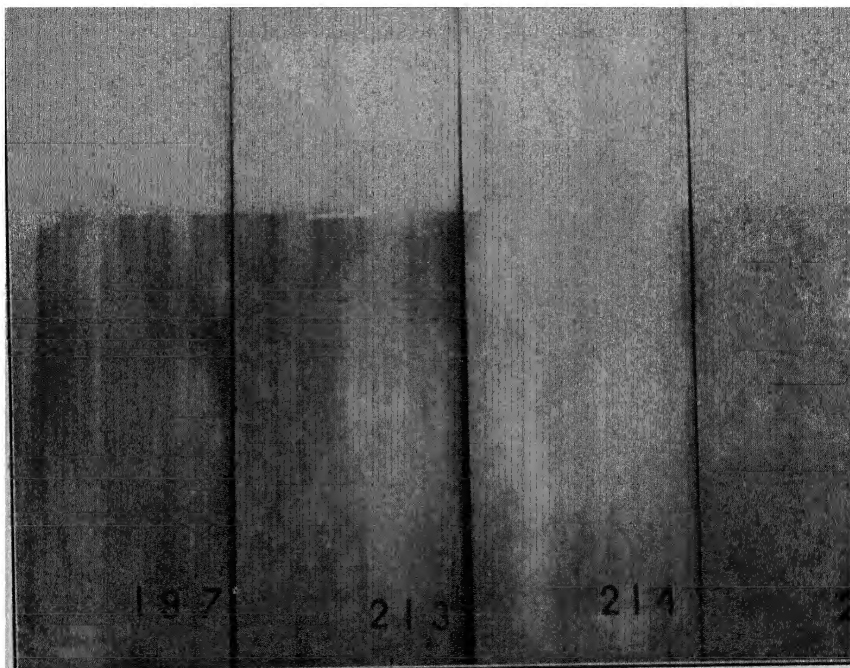


FIGURE 32. Durability of aluminum paint top coats in combination with different priming paints; panel No. 197 primed with aluminum paint, No. 213 blue lead, No. 214 red lead-zinc oxide, No. 215 basic lead chromate.

five panels of Fig. 31 include a comparison of aluminum paints made with vehicles containing synthetic resins of these types. The first panel (No. 463) was given 2 and 3 coats of aluminum paint made with an alkyd resin vehicle; the paint on No. 464 was made with a Bakelite resin varnish; No. 466 with Amberol resin varnish; No. 467 with ester gum varnish; No. 468 with coumarone resin varnish. The rust spot on the center lower half of panel No. 463 resulted from mechanical injury to the film. All except the alkyd resin vehicle were of about the same length in oil—40 to 50 gallons. The photograph was made after the panels had been exposed for $4\frac{1}{2}$ years. The panels were all in about the same condition, with little or no rusting on the 2-coat area, with the

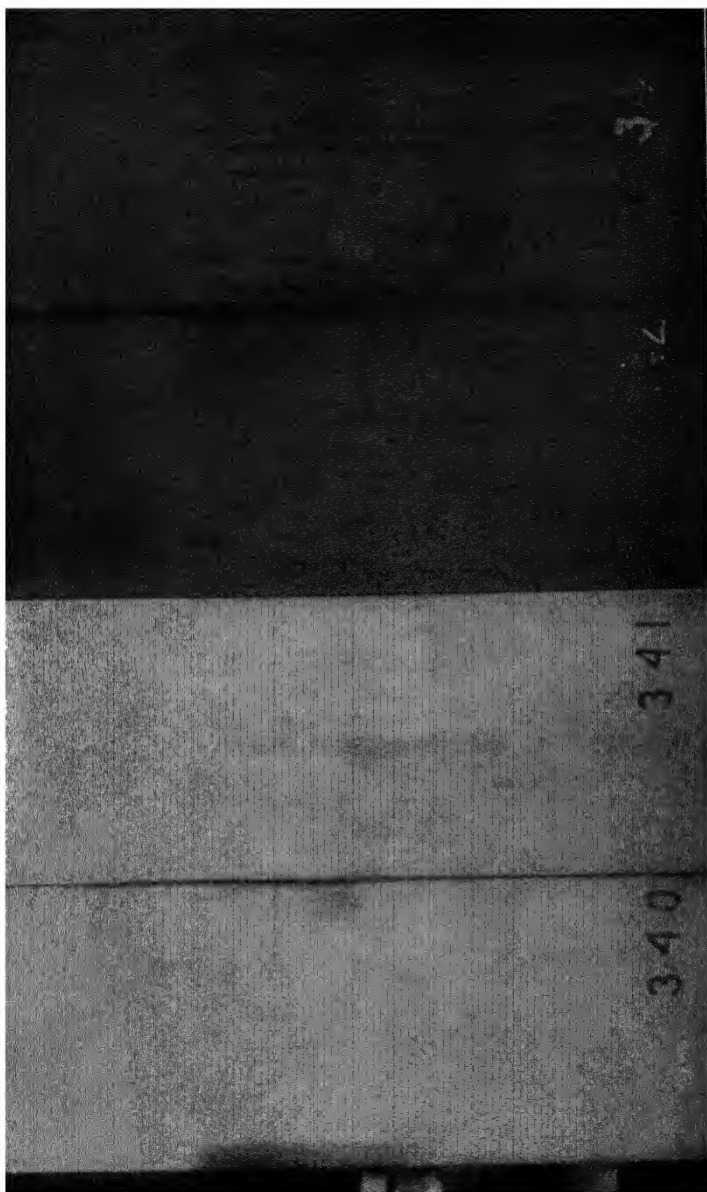


FIGURE 33. Comparison of the durability of top coats of aluminum paint on panels Nos. 340 and 341, and graphite paint on panels Nos. 342 and 343.

exception of the one coated with the paint made with the ester gum varnish. Panel No. 467 was obviously showing loss of protection in the two-coat area, even though the rusting was still not serious.

In the tests analyzed in Fig. 30, the aluminum paint was applied directly over bare steel; no special primer was employed. This procedure was followed in order not to complicate the test by introducing another paint. It was recognized, however, that by the use of certain primers under the aluminum paint an even better paint system might be built up. One test to illustrate this point is shown in Fig. 32. Panel No. 197 was primed with aluminum paint made with a varnish vehicle meeting the specification on page 201; panel No. 213 with a paint containing 74 per cent blue lead and 26 per cent boiled linseed oil; panel No. 214 with a paint containing 62 per cent red lead, 12 per cent zinc oxide, and 26 per cent oil and drier; panel No. 215 with a paint containing 84 per cent basic lead chromate, American Vermilion, and 16 per cent oil. The red lead used on panel No. 214 was the grade known as 85 per cent red lead and contained 15 per cent PbO ; the grade containing 98 per cent Pb_3O_4 is generally considered now to give better results. Each panel received a top coat of the same aluminum paint over the lower part and two coats over the upper third. The photograph of Fig. 32 was taken after four years' exposure. The basic lead chromate was in perfect condition, although for some reason it seemed slightly darker than the other panels. The panel primed with red lead stood next in order and showed only very slight sign of failure on the 2-coat area. The panels primed with aluminum paint and blue lead were in about the same condition and showed appreciable rusting in the 2-coat areas. With different formulation, somewhat different results as to life might be obtained. These results, however, are believed to give a representative comparison.

Comparison with Other Paints.

A comparison with other paints is sometimes helpful in evaluating a paint. The relative merits of aluminum paint in comparison with red lead, blue lead, lead chromate, etc., as priming coats for steel have already been briefly discussed. In Fig. 33 is shown a comparison of aluminum paint with another well-regarded paint as top coats. Panels 340 and 341 were given a priming coat of red lead, followed by one coat of aluminum paint in varnish vehicle on the lower two-thirds of the panel, and two coats on the upper third. Panels 342 and 343 were primed in the same way with red lead and given one and two coats of oil-base graphite paint of a standard make. After exposure for four years, the aluminum paint shows almost no signs of failure in the two-coat areas, whereas the graphite-pigment paint is in rather bad condition and shows heavy rusting, although still in good condition where three coats were applied.

The steel panels in Fig. 34 give a comparison between aluminum paints and standard white paints. All of the panels were given a priming coat

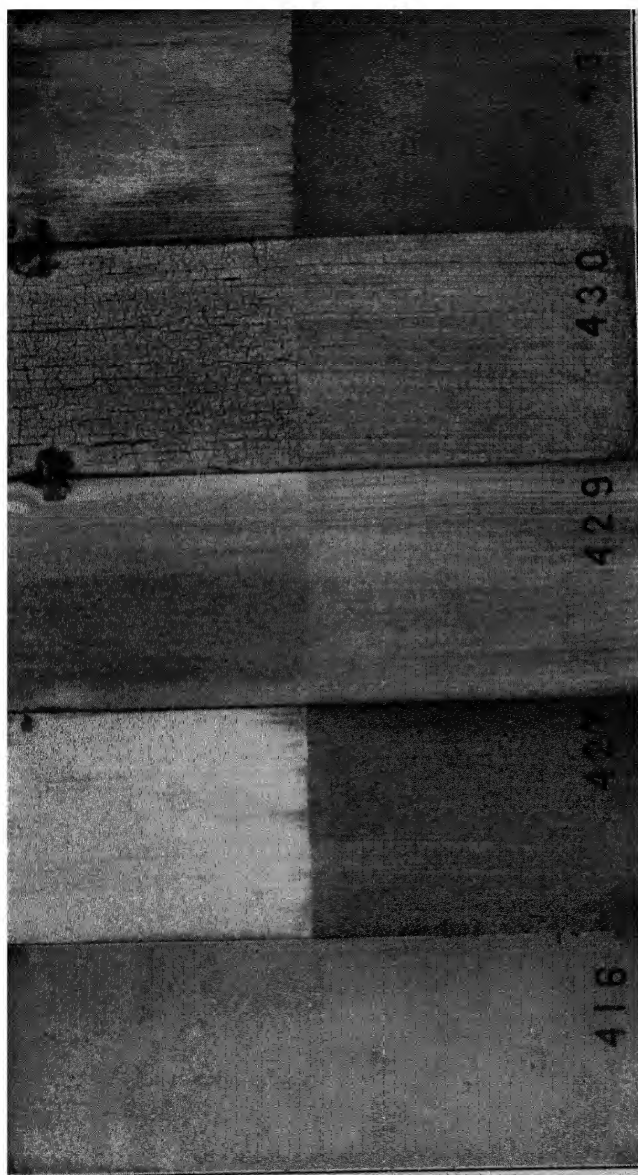


FIGURE 34. Durability of aluminum paint in comparison with other light colored paints as top coats; panel No. 416, aluminum paint; No. 427, titanox; No. 429, white lead-zinc oxide; No. 430, white lead; No. 431, lithopone-zinc oxide-inert; after exposure at New Kensington for 4 years.

of linseed oil pigmented with iron oxide and zinc chromate. They were then given one top coat on the lower half and two coats on the upper half in the following order: aluminum paint (No. 416); titanox (No. 427); white lead-zinc oxide (No. 429); white lead (No. 430); and lithopone-zinc oxide-inert (No. 431). The photograph shows these panels after 4 years' exposure at New Kensington. The aluminum paint is still in good condition in both one and two coats over the primer. The titanox has maintained its color well in the two-coat area, but it has chalked so heavily that little is left on the lower half, where only one coat was applied over the primer. Various types of failure by checking and cracking are exhibited on the other three panels.

Figure 43 on page 109 shows the results of a shorter exposure (18 months) of similar panels in Houston, Texas. Qualitatively, the same results were secured but in a shorter time at the Southern exposure.

Preparing Steel for Painting.

Almost as important as the painting itself is the preparation for painting. Paint that does not properly adhere will offer little or no protection to the surface underneath. The broadest generalization which can be made is that only a "clean" surface is in condition to be painted. Rusty, dusty and greasy surfaces are not clean from the painter's viewpoint.

Iron and steel are generally painted to protect from corrosion. If the surface is free from rust, dust or grease or any loosely adherent material, it is usually ready for the priming coat. Very frequently, however, it is a rusty surface which must be prepared for painting.⁸ If rust and scale are not properly removed, corrosion may continue beneath the paint film and cause eventual peeling of the paint as well as destruction of the metal. The character of the rust will indicate the treatment necessary. If it is deep and adherent, the use of steel scraper, chisel and hammer may be required. Sand-blasting is an excellent method but is not always available. Where sand-blasting is employed, the priming coat should be applied promptly to prevent rusting before painting. The wire brush, particularly the motor-driven brush, is also effective where loose scale and rust are to be removed, but its use must be supplemented with the chisel where corrosion is deep. In special cases, pickling may be resorted to, but the surface must be washed clean and dried, followed by prompt painting to prevent rusting. Mill scale, where present, should also be removed by these methods before painting. Sometimes weathering before cleaning assists in removing mill scale. While the corrosion started in this way loosens the mill scale, it is probable that the corrosion itself is detrimental to the preservation of the steel, and the practice is disapproved by many.

Where the surface has been previously painted and the paint is in sound condition, care should be taken to see that the surface is free from dust, dirt, grease and oil. Special attention is required, however, where the

old paint has been applied over a rusty surface, for the paint will often be found to be scaling and peeling. All such loose paint should be carefully removed and all rusty metal cleaned as thoroughly as possible.

Where the painted metal must resist particularly corrosive conditions, or where the finish must show the very best adhesion, as on automobile fenders and other parts, the metal surface should not only be clean, but chemically passive or non-reactive. When moisture penetrates a paint finish and reaches a passive metal surface, it is not likely to injure the adhesive bond between paint film and metal. Paint adhesion on iron and steel is improved by treating the metal with a solution of phosphoric acid and grease solvent, rinsing and drying, followed by painting.¹⁴ A more substantial phosphate coating applied by a hot solution of phosphoric acid, metallic acid phosphates and an oxidizing agent, known as "Bonderite," is being successfully used in preparing steel for painting.⁴ Another treatment, known as Granodizing, applies a coating of zinc phosphate electrolytically, which is said to be very effective. A thinner but more flexible surface preparation is effected by treating the steel surface with a hot solution of chromic acid (Cromodine Process).¹⁴ A very extensive art of surface preparation for painting has been developed, and the literature should be consulted for more detailed information.

Finally, and in every case, the steel should be dry. Paint will not properly adhere to a wet or damp surface; peeling and blistering are the result. Freezing weather, as well as wet weather, should be avoided for exterior painting. In cold weather, sufficient moisture may condense on metal to cause blistering and peeling.

Priming Coats for Steel.

The major volume of metal to be painted is what is generally termed structural steel. Maximum protection against corrosion during the life of the structure is usually the objective in painting structural steel. The painting system which appears to fulfill these conditions best is one which places next to the metal a pigment which exerts specific chemical protection against corrosion and which provides in the top coats high resistance to moisture penetration, adequate mechanical protection, and resistance to weathering. Red lead has a well established reputation as a rust-inhibitive pigment for priming coats on steel.¹⁸ The chromates, and particularly zinc chromate, also rank high as rust-inhibitive pigments. The use of zinc chromate in priming coats for metal is increasing as its merits become better known. Other pigments, such as aluminum powder, form durable paint films but exert no specific chemical action in preventing rust formation. Aluminum is electro-negative to iron, and hence may be considered protective in any electrolytic reaction with iron. Probably, however, the film of oxide and polishing agent on the powder interferes with such action, so that it cannot be considered as a "definitely inhibitive pigment. That does not mean, however, that

under many conditions aluminum paint in itself does not make a good primer.

Two coats of aluminum paint have given good protection on steel for extended periods, in one case as long as seven or eight years. In this latter case, the vehicle was a varnish having a viscosity of tube C, a non-volatile content of 55 per cent, and easily passed a Kauri reduction test of 60 per cent. Many users have found aluminum paint to be a satisfactory primer and have employed aluminum paint for both ground and top coats. Nevertheless, there are certain conditions under which it would seem desirable to use a primer with a strongly inhibitive pigment. One such condition is where corrosion has already started in more or less aggravated form, and where cleaning of the surface cannot be thoroughly carried out before painting. Where protection against severely corrosive conditions is desired, it is also best to use a strongly inhibitive priming coat. It is as the top coats for protecting metals that aluminum paint has found the widest use.

Painting Steel.

One coat of any paint is inadequate protection for iron and steel or wood because of the almost unavoidable defects in the continuity of a single coat. Such defects result from brush marks, pinholes and the like. It is sound practice, therefore, to use at least two coats of aluminum paint for exterior work. The fine hiding properties of aluminum paint may give a one-coat job such an excellent appearance that a second is considered unnecessary. Experience indicates, however, that two or more coats are required for good protection. On important structures the use of at least three coats of paint is considered good practice. Also in some plant and factory structures, the interior conditions are such as to require fully as complete protection for iron and steel as if the metal was exposed to the weather. This is particularly true where moisture may condense on the painted surface and remain for extended periods.

In the application of aluminum paint by brush, much the same directions can be given as for non-metallic pigment paints. Aluminum paint spreads rapidly and smoothly. A minimum of brush work is therefore necessary to secure proper covering. The leafing of the powder helps in the leveling of the paint film and tends to eliminate brush marks and like defects. Excessive brushing is a detriment to the appearance and smoothness of the film, as there is a tendency to "ball up" the aluminum particles with long-continued brushing. The most uniform appearance is obtained when the finish strokes are all made in the same direction. The paint should be kept well stirred in the container to prevent settling.

Aluminum paint is readily applied by paint spraying apparatus. The consistency should be adjusted, if necessary, to secure proper flow, but it is no different from other paints in this respect. The paint container should be provided with agitation to maintain uniform suspension of pig-

ment in the vehicle. The usual spray painting technique can be employed. In building up a durable paint coating, it is essential that each coat be given ample time for drying before applying the next coat.

An important advantage in connection with the use of aluminum paint in spray equipment, as also in brushing, is the fact that the aluminum powder is non-poisonous. It is made from the same material which has proven entirely acceptable for cooking utensils.

Aluminum paint can be applied by the roller coating method. A paint with good leveling characteristics is essential if a smooth uniform surface is to result. The suitability of the paint can be best ascertained by trial. If the coated sheet is to be fabricated, the film—after baking—should have the toughness necessary to stand any forming operations.

Application of Aluminum Paint by Dipping.

The application of aluminum paint by dipping presents a number of problems which are only gradually being solved. In most dipping operations, a substantial volume of paint is maintained from day to day in the dip tank. Continued standing of the mixed paint eventually results in loss of leaf, brightness and covering power. In addition, agitation is usually necessary to keep the pigment in suspension, and this agitation accelerates paint deterioration along the lines indicated.

Several procedures are employed where dipping seems the only practical method. The volume of paint is first reduced to a minimum, so that fresh paint can be added frequently with a minimum carry-over from day to day. A powder or paste with very stable leafing characteristics is the next requirement, and finally, a vehicle in which leafing shows no loss, or at worst, a gradual decrease. Agitation should then be reduced to the minimum consistent with satisfactory stirring. By careful attention to these details, a reasonably satisfactory result can be obtained.

Painting Aluminum.

Aluminum paint has been found eminently adapted to the painting of aluminum and its alloys because of its durable, flexible film of high moisture-proofing power. As in the case of steel, an aluminum surface ready for painting should be clean and dry. In the painting of structural aluminum, no special surface treatment is necessary unless the painted metal is to be kept moist for extended periods. Where the metal is to be subjected to severely corrosive conditions, the surface should be rendered passive by suitable treatment before painting. The best adhesion is secured by anodic oxidation, although results satisfactory for many purposes are simply secured by chemical treatment.^{5, 6} Anodic oxidation in chromic acid has long been employed on aluminum aircraft parts prior to painting, particularly on pontoons and other parts of seaplanes.¹ The Alumilite process is also well adapted for this purpose. Chemical treatment with suitable phosphoric acid-alcohol solutions, while not as effec-

tive as anodic coating, is helpful in promoting adhesion and quite useful for many purposes.

Generally, aluminum paint is entirely satisfactory as a priming coat on aluminum, but where particularly severe conditions are to be met, zinc chromate can advantageously be used in the primer.¹⁶ This pigment, with its soluble chromate content, has a specific chemical action in inhibiting corrosion on aluminum, as well as on iron and steel. It can be used in a long oil varnish vehicle similar to that employed for the top coats of aluminum paint. Iron oxide can advantageously be used with zinc chromate in such a primer.

An accelerated test for evaluating finishes on aluminum under conditions involving periodic immersion has been developed by Aluminum Company of America.⁷ The test comprises immersion of the test pieces in salt water for a set period, followed by exposure to the atmosphere and drying; the two conditions are repeated in cycles. Test specimens are built in the form of small boxes (10×10×7 inches), open at the bottom and vented at the top. These boxes are assembled by riveting or electric welding and in a manner closely simulating actual aircraft practice. The surfaces of these boxes are prepared in various ways and paint coatings applied. In studying various methods of surface preparation, the same paint coating is used on all boxes. After the coating is thoroughly dry, the specimens are placed in large wooden tanks located on the roof of a plant at Edgewater, N. J., opposite New York, N. Y. Brackish water from the Hudson river is pumped into a supply tank which automatically drains, when full to the first test tank, thence to the second and third tanks, and is finally discharged. The water in each tank rises to a level about 3 inches above the specimens before it passes to the next tank. The specimens are thus alternately wet and dried at about 45-minute intervals. The extreme lower portions of the specimens are continuously immersed. As the apparatus is located out of doors, the specimens are also continuously exposed to the weather in addition to alternate immersion in the salt water. This test, of course, cannot be continued during freezing weather. In many instances, failure of the poorer coatings occurs in 2 months, but many of the better coatings have withstood 2 or 3 seasons or more of such testing.

To adequately meet service conditions such as represented by this test, the advantages of proper surface preparation, both for steel and aluminum, soon become obvious. Anodic coating prior to painting, for example, is quite general practice where aluminum alloys such as 24S, 17S or duralumin are used in sea-plane construction. The advantages of zinc chromate as a primer-pigment have been demonstrated by these tests. Aluminum paint has been satisfactory as a primer, and as a top coat, no superior paint has been found. Figure 35 shows two aluminum alloy boxes which have been in the alternate immersion test for two years, or rather, seasons, for the test was discontinued during the winter. Both of these boxes have been given a priming coat comprising a 50-gal-

lon Bakelite varnish pigmented with zinc chromate. The box on the left has been given a top coat of aluminum paint made with Standard Lining powder in a 50-gallon Bakelite varnish. The box on the right has been given a top coat of a gray enamel made according to Tentative Navy Specification M-67-F,¹⁵ which likewise employs a similar, though not identical, Bakelite vehicle. The lower part of each box shows some staining, caused by the deposition of solid matter from the water in which it was immersed, but on the box given the aluminum paint top coats there is practically no sign of corrosion and the paint coating is in good condition, both inside and out. On the box with the gray enamel top coat there is bad blistering and flaking of the gray paint on the lower

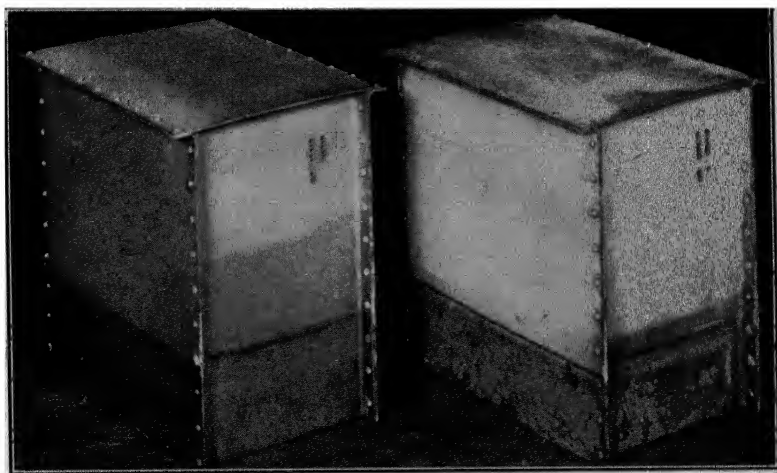


FIGURE 35. Aluminum alloy (17ST) boxes after alternate immersion test in salt water for two seasons.

area which was continuously immersed, and some signs of corrosion and paint failure on the upper area as well. This, of course, is only one test, but continued experience year after year has demonstrated that aluminum paint, preferably in a synthetic resin vehicle, is the most serviceable paint which can be chosen for this and similar applications.

In painting structural aluminum alloy which is not to be subjected to immersion, no special electrolytic or chemical preparation of the surface is usually necessary. The best painting system which has been found combines an inhibitive primer containing zinc chromate with top coats of aluminum paint, preferably in a durable synthetic resin vehicle. This combination has been found effective in protecting structural steel, but even better adhesion and durability are observed on aluminum and its alloys, which are naturally, of themselves, much more resistant to corrosion than is steel.

Painting Magnesium.

Magnesium presents a very special problem in painting if even fair results are to be secured. This may be ascribed to the reactive character of the metal and the difficulty of forming adherent, impervious and durable protective films on the surface. Whitmore¹⁹ has pointed out that when magnesium is immersed in water or salt solutions, a relatively high degree of alkalinity is developed from corrosion of the metal. In some cases, a pH of 12 was reached. This may explain in part, as Whitmore points out, the difficulty of making paint coatings adhere to magnesium when the painted metal is subjected to continuous or periodic wetting. Alkaline peeling of paint films is a common source of paint failure, according to Evans.⁸ Some treatment to passivate the magnesium surface and form a protective film seems necessary if paint coatings are to adhere satisfactorily.

Chemical treatment in a nitric acid-sodium dichromate solution is one of the preferred surface treatment methods. Magnesium treated with this "chrome pickle" will remain passive during several days' immersion in water, according to Winston, Reid and Goss.²¹

The best available surface preparation should be followed by an inhibitive priming coat containing zinc chromate pigment. The top coats should be as impermeable to moisture as possible, consistent with the flexibility or toughness necessary in the paint film; three coats of aluminum paint in a durable phenolic-resin vehicle are recommended.

Painting Zinc.

Galvanized iron and zinc frequently give trouble in painting because of the character of the surface. The problem is one of long standing and many treatments have been recommended for increasing adhesion of paint films on zinc surfaces. Fundamentally, the difficulty may be due in part to the fact, pointed out by Whitmore,¹⁹ that zinc, as well as magnesium and cadmium, reacts alkaline in contact with water, although not to the same extent as the last two named metals. Zinc, though usually placed below aluminum in the electromotive series, is electronegative to aluminum (higher solution potential) when in contact with it in a salt solution. This apparent anomaly is probably the result of the inability of the zinc to form a passivating oxide film as successfully as does aluminum. Wing²⁰ has identified zinc formate on painted zinc surfaces, which he ascribes to reaction between the zinc and formic acid coming from the oxidation of the vehicle in drying. The successful painting system for zinc surfaces should therefore combine a passivating surface treatment with a durable paint film, resistant to moisture penetration. Treatment with phosphoric acid solutions similar to those used with steel and aluminum has been found helpful. Nelson,¹¹ however, recommends fine grit blasting of the surface, or treatment with an acidulated toluol-alcohol-carbon tetrachloride mixture, followed by thorough wash-

ing, or weathering for three to six months, as surface preparation for painting.

Walker and Hickson¹⁸ report "good results with aluminum paint as a primer for galvanized iron." They also look with favor on the use of phosphoric acid-alcohol solutions in preparing zinc surfaces for painting. In Figure 25 is shown an exposure test in which two coats of aluminum paint have shown good adherence and protection for 12 years when applied over an untreated galvanized steel surface.

Tinting Aluminum Paint.

Tinting aluminum paint presents some unusual difficulties and some special opportunities for unusual effects. Aluminum bronze powder is made in only one color,—the natural one. It is true that aluminum powder can be dyed all the colors of the rainbow, but these powders are relatively expensive and the colors too fugitive to resist any extended exposure to light and weather.

The leafing of aluminum powder effectively hides substantial quantities of colored pigments added to aluminum paint. For example, up to about 3 per cent of red lead can be added to aluminum paint without any marked tinting effect. If larger quantities are added, tints are secured because of the mass effect of the pigment and because the free leafing of the powder is interfered with. If, however, the aluminum powder is allowed to stand mixed with the vehicle until leafing has practically disappeared, a uniform tint can be obtained. Under such conditions, a uniform distribution of aluminum powder and colored pigment throughout the paint film is possible. Some unusual effects in decorating can be secured by such tinted paints, particularly in combination with stenciled patterns. The aluminum powder lends to the paint a certain silky luster which appears to give depth to the surface.

If no specific color is necessary and only a different tint is wanted, the effect can best be obtained by the addition of Prussian blue paste. This practice is sometimes employed to distinguish between two field coats of aluminum paint on bridges and other steel structures. With most vehicles, 2 ounces of Prussian blue (dry basis) to 2 pounds of standard aluminum paste will give a satisfactory tint if the mixed paint is allowed to stand 24 hours before using, in order to minimize the leafing tendency. In other cases, 3 or 4 ounces of the blue pigment may be required to give a satisfactory tint. If the aluminum powder leafs readily in the mixed paint, a uniform tinting effect cannot be expected. To secure the maximum tinting effect, the paint should be applied by brushing and not by spraying.

Polychromatic Lacquer and Enamels.

A type of finish which has found extensive use in automobile finishing, sometimes called "polychromatic," combines a pigmented lacquer or synthetic resin varnish with a very small amount of the *finest* mesh alu-

minum powders. In order to produce the best effects it is essential that the vehicle be as nearly water-white as possible and that it show a minimum of "yellowing" on aging. Nitrocellulose lacquers may be employed, but alkyd resin varnishes are the most widely used for the enamel finishes. The colored pigments should have low tinting strength in order to enhance the metallic appearance and depth of the film. All leafing of the aluminum powder must be destroyed or it will leaf irregularly, causing loss



FIGURE 36. Aluminum paint on telephone exchange equipment. (Courtesy of Bell Telephone Laboratories.)

of gloss and a non-uniform finish. The leaf may be destroyed as, for example, by grinding a heavy mixture of aluminum powder and clear vehicle for a short time on a mill. This mixture, or "aluminum base" as it is called, may then be used to tint the colored coating by mixing in small amounts until the desired effect is obtained. A colored finish with a semi-metallic lustre, which gives an attractive and striking appearance is the result.

Baked Coatings.

A common finish for metal articles, such as apparatus, furniture, equipment, and the like, is a baked lacquer or enamel. Such finishes can be made hard and durable, are quickly applied, and dry quickly, so that they can be handled on a mass production basis. Aluminum paints and lacquers can be baked, and in fact, when the proper composition is selected, they are especially adapted for this method of application. Light colored enamels show a tendency to darken on baking, particularly if the temperature of baking is high, as is frequently the case. On the contrary, aluminum paint, enamel or lacquer is practically immune to such darkening; this is a very important advantage. For baked finishes, the vehicle most widely employed is a varnish. The varnish should be one which will air-dry to a fairly hard film, and it should be of rather fluid consistency. Many of the synthetic resin varnishes are very satisfactory. After applying the paint, preferably by means of spraying, it can be baked at temperatures of 125° to 175° C. (about 250° to 350° F.) for periods of one-half to three hours, depending upon the temperature, the hardness of film desired, and the particular varnish employed. Several coats may be applied in this manner and no discoloration of the film of aluminum will result. It has been found that a smoother surface results through the use of a Lining powder or aluminum paste.

Baked aluminum finishes have a bright metallic appearance, do not soil or mar easily with handling, can be readily cleaned by washing, and are very durable. Their use on telephone exchange equipment is discussed on page 102.

Polished Aluminum Finish.

A finish resembling polished aluminum can be given an object of metal or wood by the following process: The object should first be given a priming coat of aluminum paint, which should be allowed to dry thoroughly. It should then be sanded lightly to secure a perfectly smooth surface. A top coat of clear varnish should then be applied and allowed to dry until very tacky. Baking the finish for a short time is a convenient means of reaching this stage. When just the right degree of stickiness is attained, as determined by experiment, dry aluminum powder should be dusted over the surface. The surface should then be rubbed or burnished with a cloth until a smooth, mirror-like metallic finish is secured. With a little experience it is possible to produce a very effective finish. In some cases the priming coat can be omitted if desired.

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Chapter 6.

Special Properties and Uses of Aluminum Paint

Reflectivity.

One of the obvious as well as useful properties of aluminum paint is its brightness. Sheet aluminum, clean and bright, may have a reflectivity as high as 85 per cent, or even higher, according to the composition and surface condition. This value is an upper limit towards which aluminum paint may reach but which it probably cannot attain. As previously mentioned, abrasion during stamping tends to darken the metal. The vehicle in which the powder is suspended may also have an effect, and the distribution of powder in the dried paint film is likewise a factor in determining reflectivity. As a result, the maximum reflectivity observed with aluminum paint films is about 75 per cent, or slightly higher. In practice, the average performance of good paints will vary between 60 and 75 per cent. Lower values may also be observed with poorly leafing paints and paints made with dark powders.

The reflectivity, reflectance, or reflection factor of a surface is defined as the ratio of the total light reflected to the total light incident upon the surface.

Naturally, the quality of the aluminum powder is an important factor in the brightness of the paint film which can be made with it. Powders which are "dark" or "dull" cannot be expected to give films of maximum brightness. The Extra Brilliant grade of powder usually has a slight advantage—2 or 3 per cent reflectivity—over Standard Varnish powder. The Extra Brilliant powder, however, with its larger proportion of coarse flakes, gives a somewhat rougher paint film. There is little difference in reflectivity to be noted between paint films made with Standard Varnish and Extra Fine Varnish, although the Extra Fine powder gives a film of smoother texture. Aluminum paste gives a bright and smooth paint film.

At first thought, the color of the vehicle might be considered to have a substantial effect upon the color and brightness of the paint film. Measurements show, however, that within wide limits, this effect is usually inappreciable. Aluminum paint made with crystal clear oil had no higher reflectivity than one made with a deep orange red oil. With a good leafing powder, the film of oil above the metal particles is usually so thin as to have little effect on the resultant color and reflectivity. If a powder of good leafing characteristics is employed, it is usually unneces-

sary, therefore, to employ a very light colored vehicle to secure a bright paint film.

The degree of leafing does, however, have an important influence on reflectivity. Unpolished powder gives a paint film without leafing and has about 10 per cent lower reflectivity than one made with the same grade of polished powder. An aluminum paint, made with paste in an alkyd resin vehicle of good leafing characteristics, showed a reflectivity of 78 per cent in a single sprayed coat. The same paste, however, in an alkyd resin vehicle which permitted no leafing, showed a reflectivity of only 55 per cent—when applied in the same manner. In the case of aluminum-pyroxylin finishes, where no leafing occurs, the film usually has a “frosted” surface but may nevertheless be very bright in appearance.

The maximum reflectivity of aluminum paint is developed in one, or at best, two coats, even when applied over a black or dark surface. This result may be ascribed to the complete opacity of the aluminum flakes.

A metal panel with two coats of aluminum paint made with Standard Varnish powder was submitted to the Bureau of Standards for measurement of its reflectivity. The Bureau of Standards Report, dated Feb. 28th, 1926, contains the following statement regarding this test:

“The measurements were made on a Taylor reflectometer employing a sensitive Weber photometer to obtain the points of photometric balance. The reflection factor was obtained by four observers at five different points on the sample. These five test points were: The center of four equal corner rectangles including the entire area, and the center of the specimen.

The mean diffuse reflection factor of the painted plate was found to be 0.629.

The greatest deviation from the mean of all of the test points for the result obtained at any one test point was 1.05 per cent, and all of the observers agreed on the average factor to within one-tenth of one per cent.”

The Taylor reflectometer (see page 44) employs a directed beam of light with an integrating sphere, and gives directly the total reflectivity without the use of a standard comparison sample. A similar metal panel coated with two coats of aluminum paint was later submitted for a determination of its reflectivity with completely *diffused* illumination.¹⁹ The Bureau of Standards, in its Test Report, dated Feb. 14th, 1931, states as follows:

“The reflectance of the aluminum paint has been measured relative to that of magnesium oxide, under completely diffused illumination, and in a direction approximately normal to its surface. A value of 0.645 was obtained for the quantity thus defined and with illumination of sunlight quality. The material is very nearly non-selective in reflectance throughout the visible spectrum.”

The magnesium oxide standard referred to is generally assumed to have a reflectivity of 98 per cent, so that the reflectivity of aluminum paint under the conditions defined would be 0.632 or 63.2 per cent. Viewed at angles other than normal to the surface, the reflectance with completely diffused illumination would be higher than the value given, so that the total integrated reflectivity would also be greater. The aluminum paste pigments now available give even brighter paint films.

Aluminum paint also has a high reflectivity for ultraviolet light, which is a desirable characteristic for many uses. Table 6 contains data on the ultraviolet reflectivity of aluminum paint and two types

TABLE 6.

REFLECTION-FACTORS OF VARIOUS MATERIALS FOR LIGHT FROM A SMALL TUNGSTEN LAMP, AND AT $\lambda 2967$ IN THE ULTRAVIOLET.

According to A. H. Taylor,²³ Lighting Research Laboratory, General Electric Company, Nela Park, Cleveland.

	Per cent Reflection-Factor	
	For Light	At $\lambda 2967$
Aluminum paint	75	65
White enameled metal	65 to 75	5 to 8
White lead paint, flat	80	27
White plaster	90	50

of white paints, together with the reflectivity of these paints for visible light.

Painting Interiors.

The reflectivity of painted surfaces, walls and ceilings may be a factor in determining lighting efficiency. The part paint plays in "better lighting" will depend to some extent, however, on the methods of lighting employed. Where artificial lighting is entirely of the indirect type, for example, the reflecting surfaces should be of maximum brightness and good diffusing characteristics. Flat white paints fulfill this requirement satisfactorily. In small rooms and offices, particularly with smooth walls and with non-uniform illumination, aluminum paint does not appear to best advantage.

Aluminum paint gives what is known as "spread reflection"—reflection intermediate between specular and diffuse but closest to the latter. The degree of diffuseness can be controlled to a considerable extent by the paint formulation and also by the character of the surface to which it is applied. Aluminum paint, for example, appears to best advantage on a rough plaster wall. On smooth plaster, it may appear dark from many angles, particularly where the illumination is non-uniform. The Bureau of Standards measurement (page 96) showed

the reflectance of an aluminum painted panel, when illuminated by completely diffused illumination, to be over 63 per cent. In factory and works interiors, aluminum paint shows to good advantage because beams and surfaces at all angles help to give uniform illumination.²¹ It has been successfully used in applications of this kind, and this use has been economical because of the ability of aluminum paint to hide and cover in one coat.⁴

Efficient lighting, of course, demands other conditions than bright walls and ceilings. In fact, walls are frequently painted a darker tint

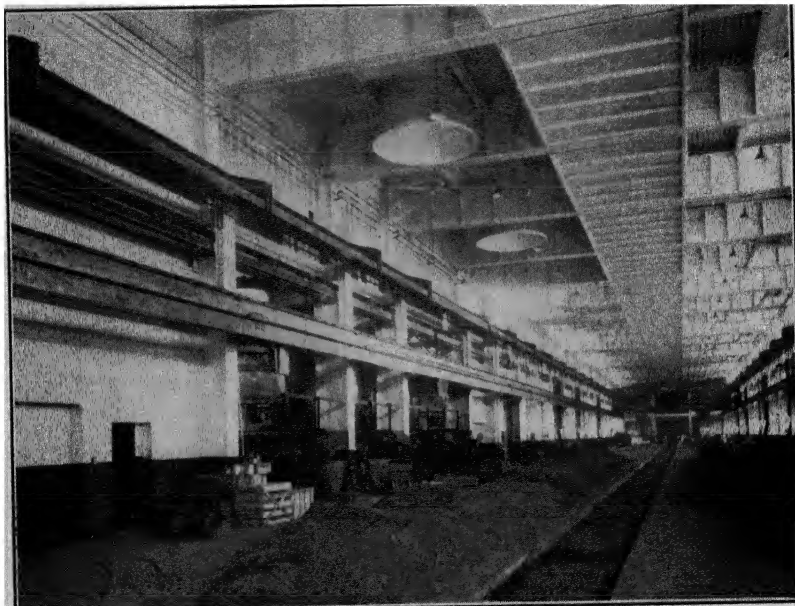


FIGURE 37. Plant of Westinghouse Airbrake Company, Pittsburgh, showing high lighting efficiency of aluminum painted interior.

than ceilings, since they come within the line of vision oftener and too bright a background is undesirable. The light available must be adequate for the visual task, and experts in this field are recommending higher levels of illumination than has been customary in the past.

Light distribution upon the work field should be uniform. Logan¹⁰ points out that too much diffusion of light is objectionable, as is too little diffusion. The absence of shadows causes an object to look flat instead of appearing in relief and gives the effect of poor perspective, which makes it difficult to judge distance and proportions with accuracy. On the other hand, shadows should not be too sharp or too dark, or the observation of detail becomes difficult. Lighting may, in fact, be just as important as light.

There appears, moreover, to be a great deal of fruitless discussion about relatively small differences in the reflectivities of different surface finishes in connection with lighting efficiency. Luckiesh,¹⁷ who is Director of the Lighting Research Laboratory at Nela Park, Cleveland, has by his researches and publications brought to the public's attention what he calls the Science of Seeing. One of the important factors which he has emphasized, concerns the relative values of various levels of illumination as aids in seeing. To quote Dr. Luckiesh—

“The new science of seeing has altered old ideas of foot-candles and has crystallized some vague ones. The foot-candle is a physical unit, or at least has been considered as if it were. Actually, a foot-candle is valuable to human seeing machines only in proportion to the aid it renders in seeing. Foot-candles, as physical units, can be added arithmetically because they are constant in value. However, from the viewpoint of seeing, a foot-candle is no longer of constant value. One foot-candle, when added to one foot-candle, is a real aid to seeing. But when one foot-candle is added to 10 or to 100 foot-candles it is relatively insignificant. Of course, this has been known, but the predominance of the physical sciences and the absence of a science of seeing have prevented a full recognition of this in lighting practice. It is now well established that foot-candles scales should be geometric and that the intensity of illumination must be doubled if a significantly noticeable improvement in seeing is to be achieved.

In brief, the new science of seeing reveals important inconsistencies and many ridiculous foot-candle recommendations in the past empirical era of lighting practice. The old codes of lighting, in which foot-candle recommendations were refined far beyond knowledge, not only then but now, must be abandoned. No better suggestion has appeared than to establish about ten steps in foot-candles from 0.5 to 500 foot-candles, arranged approximately in geometric ratio using round numbers, such as 0.5, 1, 2, 5, 10, 20, 50, 100, 200, 500. In the lowest class the lighting of country highways and railroad yards might be placed for the present. And, for the present, sewing on dark goods and fine lace-making would be placed in the top class. These recommendations are by no means adequate from an idealistic viewpoint, but they represent a great advance over the present one-foot-candle age.”

In the light of this statement, small differences in the reflectivities of painted walls and ceilings can hardly have much of an effect on ease of seeing. While statements that the quantity of light in a room has been increased 25 to 50 per cent, by changing walls and ceiling to lighter colors, sound impressive, the quantitative effect upon ease of seeing may not be so important.



FIGURE 38. White-painted bridge on Illinois State highway north of Geneseo; photograph made at night under same conditions as Figure 39.

Visibility.

One of the early and still growing uses of aluminum paint is in the painting of bridges, and one of the recognized and salient characteristics of aluminum paint for this purpose is good visibility—an important consideration for motorists on modern highways. Dr. Luckiesh, consulted regarding the visibility of aluminum paint on bridges, stated:

“Visibility in this case is a matter of contrast in brightness with the background or surroundings. The brightness of a bridge member is due to diffuse reflection and specular reflection. The latter may be termed luster. The brightness of aluminum paint due to diffuse reflection is usually superior to that of battleship gray. In addition, the aluminum paint is greatly superior in specular reflection or luster. The bridge members are oriented in many directions so that the aluminum paint always reflects some lustrous high lights which in reality are imperfect images of sky and other bright areas, or of the sun or artificial light-sources. These high lights are much greater than in the case of a battleship gray, even though the latter be glossy. The brightness due to specular reflection or



FIGURE 39. Aluminum-painted bridge on Illinois State highway north of Geneseo; photograph taken by illumination from headlights of automobile; photographic conditions identical with those employed in taking photograph shown in Figure 38.

luster is of such a different order of magnitude from that due to diffuse reflection that the visibility is often almost entirely due to it. In these cases the visibility of aluminum paint is outstandingly greater than that due to battleship gray. In the rarer cases, where brightness is due solely to diffuse reflection, aluminum paint should be superior to the battleship gray, exactly in proportion to the diffuse-reflection factors of the two paints."

Gamble,¹⁰ for example, has tried to show by photographs of an 8-foot model of a highway bridge illuminated by a spot light, "the advantages of a white diffusing paint over a typical metallic luster paint as a means of improving the general night visibility." It is interesting to compare the photographs of Gamble's toy bridge with photographs made of two real highway bridges, one painted with white paint and the other with aluminum paint and which are shown in Figs. 38 and 39. These photographs, taken under identical conditions when the bridges were illuminated by the light of a motor car, showed the visibility of the aluminum-painted bridge to be quite as good as that of the white-painted bridge, and con-

firm the opinion of motorists using these bridges, that the visibility of the aluminum-painted bridge is very satisfactory.

Another question which has been raised is whether an aluminum-painted bridge would not be of low visibility in a fog. This idea is no doubt suggested by a similarity in color of aluminum paint and a very light fog. However, when analyzed on theoretical grounds, this objection did not seem a valid one, and certain experimental tests were made.

These tests were carried out on a morning when there was a very heavy fog. Two steel panels, each 8'×24', one coated with aluminum paint and the other with black paint, were set up vertically at the end of a roadway and against a white plaster wall. Six people were asked to look at the wall at a distance of about 40 yards. All six reported that they saw the aluminum-painted panel which was clearly visible at this distance, and none of the six could see the black panel, although three knew it was there and three did not. None of the group could see the black panel until they approached within about 30 yards of the panels, whereas the aluminum panel was still visible at a distance of 65 yards, which was the farthest away from the panel which the observers could get because of the buildings. The six observers were unanimous in their statements that the aluminum-painted steel was readily visible, even in this dense fog, but that the black-painted steel was of extremely low visibility.

Although the black panel against the white plaster wall might have been expected to show the greatest contrast with its surroundings, nevertheless the aluminum-painted panel was the only one which could be seen. The visibility was impeded by the fog, which lay as a blanket, so to speak, between the observers and the panels, and the aluminum-painted panel was the only one which reflected sufficient light to penetrate the fog. Whatever the explanation may be, there was no question of the superior visibility of the aluminum-painted panel:

It is a fortunate circumstance, also, that in addition to having good visibility, aluminum painted structures blend harmoniously with the landscape. Water towers, for example, painted with aluminum, acquire an architectural gracefulness, perhaps because of the light color of the paint. Aluminum painted tanks and bridges always appear appropriate and do not clash with their surroundings.

Light Finish in Telephone Exchanges.

The finish of walls, equipment, apparatus, etc., in telephone exchanges presents a variety of problems, including that of lighting efficiency. The problem and its solution have been well stated by Johnson,¹³ of Bell Telephone Laboratories.

"For some time past it has been recognized by telephone engineers generally that a satisfactory bright or light-reflecting paint on the iron framework and apparatus of central offices would do much to increase the attractiveness and better the lighting of terminal

and apparatus rooms. This in turn would pay dividends in improved maintenance conditions and in the cheerful effect on the central office personnel.

The finish used up to the present time on iron framework is black, consisting of a primer coat of steel gray protective paint,

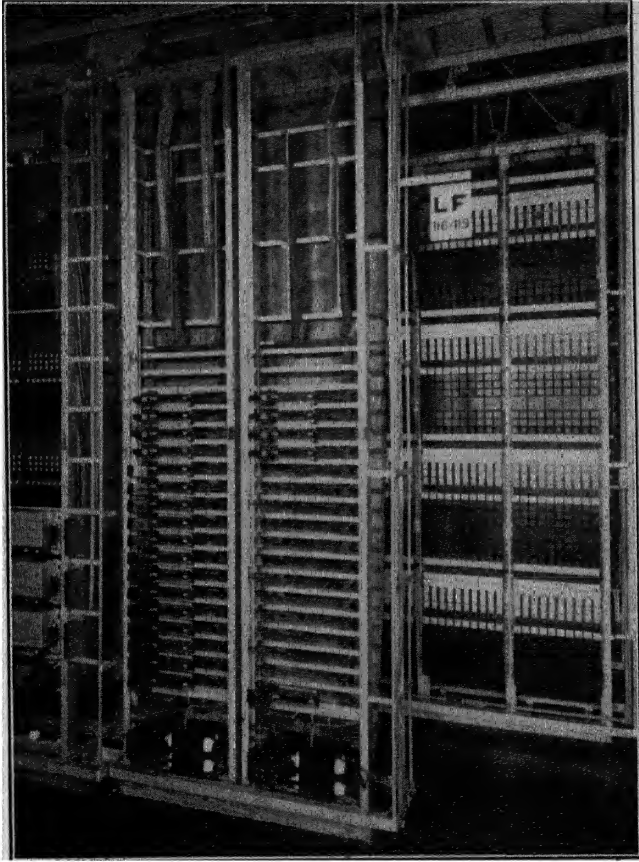


FIGURE 40. Panel system in telephone exchange; frames and part of the attached equipment are finished in aluminum paint to improve protection and lighting efficiency; note contrast with old equipment finished in black. (Courtesy of Bell Telephone Laboratories.)

and a finishing coat of black asphaltum paint, both coats applied by brush and air-dried. Finish on apparatus is also black, being generally baked japan or black lacquer. But plans have now been completed, and as soon as manufacturing arrangements can be made and merchandise stocks now on hand satisfactorily disposed

of, central offices will begin to blossom forth in spick and span coats of bright, silver-like aluminum paint and varnish.

On the new basis, all ironwork such as frames and racks, cable racks and superstructure, as well as all the various kinds of apparatus: relay and repeater covers, repeating coils and condensers, will be given an aluminum finish to replace the black finishes which are now in use."

Before selecting the aluminum finish for the Bell Telephone System, tests were made to determine its fitness in all respects. The aluminum finish was selected from a group of coatings and Knox ¹⁴ has given part of the reasons therefor as follows:

"When the investigation of these light-colored finishes was started, we were open-minded as to whether gray pigmented paints or aluminum-colored paints were best. If an aluminum paint could be developed which would adhere as well to metal surfaces and have as long life as the gray paints, it would be very desirable to take advantage of the superior reflecting quality of the aluminum paint.

After applying tests to each of the six or seven types of finishes we thought promising, the results stood out that baked aluminum-colored finishes were decidedly better than any of the others. They apparently owe this good quality to their capacity to be baked to a very hard, adherent state which is resistant to the action of soap and solvents, and still to remain light colored at the end of the baking operation. Thus, a coat of good varnish pigmented with aluminum may stand baking up to 400 degrees Fahrenheit, for one and one-half hours and still be brightly aluminum-colored. No other light-colored finish of the paint, varnish or japan types will stand baking at this temperature for more than a very small fraction of this time without suffering considerable discoloration."

Also:

"For the final evaluation of these finishes, careful comparative tests were made by Mr. Arlt. One test consisted of rubbing each finish with a wooden block under carefully controlled conditions of pressure, speed and the like. The 'woodpecker machine' was also employed to tap the end of a switchboard plug repeatedly against each kind of finish. Ductility tests were made by pressing finished sheets into a cupped shape to see how the various finishes compared as to adherence and flexibility. Under these tests the new finishes have been found to compare favorably with the old black finishes, and promise to be quite as satisfactory as we can fairly hope a light-colored baked finish to be. Gradually, our central office equipment will practically all be finished with aluminum colored coatings; and most people have only to glance at an assembly of such apparatus to feel convinced that it does represent an improvement in appearance over the old black finishes."

Aluminum Paint on Oil Tanks.

A major use of aluminum paint has been for the painting of oil tanks, with the two-fold object of protecting the steel tank from corrosion and for reducing evaporation losses. Until recent years the extent to which sunlight increased the evaporation loss from oil storage tanks was scarcely realized. In the southern oil fields of the United States, solar radiation of 4 to 5 Btu. per square foot per minute is common on clear days. On the area of a tank normal to the sun's rays, this will amount to a very substantial heat input, and unless it is properly dissipated, may raise the oil temperature many degrees.

The Bureau of Mines has published some of the data they have collected in their study of ways and means of reducing evaporation losses in the handling and storage of petroleum. The first step to be taken is to make all containers as vapor-tight as possible. When this has been accomplished, the evaporation losses are largely due to the "breathing" out of

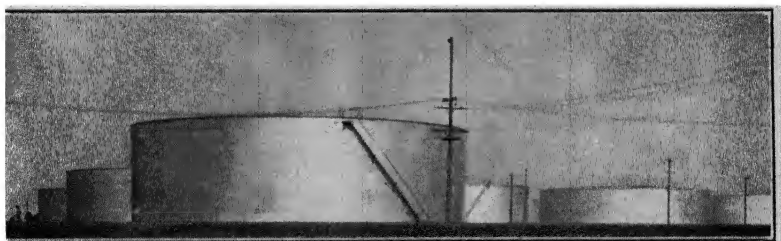


FIGURE 41. Oil storage tanks in California, protected with aluminum paint.

air saturated with light oil during the heating of the tank, and the "breathing" in of fresh air during cooling, which will be saturated with oil vapor to be expelled in the next cycle. The amount of oil vapor required to saturate the air increases rapidly as the temperature of the oil rises. The vapor pressure of a typical crude oil increased from 4 inches to 6 inches of mercury in being heated from 70° to 100° F. It is desirable, therefore, to keep the oil as uniformly cool as possible.

A practical test of the efficiency of various paints on oil tanks has been carried out by the Bureau of Mines in cooperation with the State of Oklahoma. The results of the test are reported by Ludwig Schmidt in Report Serial No. 2677 of the Bureau of Mines. Four 55,000-barrel tanks were used for these tests and they were painted black, red, gray and aluminum, as being colors much used in the oil industry. Schmidt states that "every effort was made to keep these tanks vapor-tight throughout the duration of the test. Before the initial gage was made, each tank was inspected and every leak caulked. The last coat of paint was applied after the tanks were filled with oil. The roof of each tank was painted at that time. The tanks were filled with fresh

Burbank crude pumped directly from vapor-tight lease stock tanks." This oil had an average gasoline and naphtha content of 29 per cent.

The test ran from January, 1924, to January, 1925, and the results therefore apply to average conditions throughout the year. The volume and composition of the oil were determined every month. Recording thermometers made a record of the vapor pressures in the tanks. Table 7 summarizes the results on evaporation losses.

TABLE 7.
EVAPORATION LOSSES FROM OIL TANKS IN BUREAU OF MINES' TESTS.

Color of Tank	Initial Gage Barrels	Evaporation Loss in one year Barrels	Loss in Gravity in one year A. P. I.
Black	52,058	649	.6°
Red	53,294	609	.5
Gray	53,192	547	.3
Aluminum	53,418	447	.2

The results are eminently favorable to aluminum, and this in spite of the fact, as stated in the report, "that the roof and part of the side of the tank painted with aluminum were covered with oil when a lead line on a near-by flow tank broke. The oil was not cleaned off completely for several weeks. Therefore the tank was almost black during part of the test."

Schmidt also notes that "the red, gray and aluminum tanks were located on leases that were being developed in the Burbank field. Therefore during the hot summer months the tanks were coated with a thin film of dust. The dust was usually oily, due to the large quantities of gas and oil vapor in the air, and clung to the tank tenaciously. This condition had a tendency to reduce the heat-reflecting properties of the colors and to place all of the tanks in the same class as to color. The effect of the dust was greatest on the gray and aluminum tanks. The dust was readily washed off by rains, so it did not materially affect the results when the entire period of the test is considered."

The aluminum paint showed a saving of at least 200 barrels per year compared with black paint, and 100 barrels compared with gray paint. The report concludes with the statement that the "results are believed to be conservative, and under slightly different conditions, the differences between the results obtained with the light and dark colored paints would doubtless be more marked."

If the temperature in the tank did not vary, there would be little evaporation loss from "breathing" in a tight tank, irrespective of its color. In the Bureau of Mines report just referred to, the average daily maximum variations in temperature of the four tanks were as follows: black, 32° F.; red, 29° F.; gray, 25° F.; aluminum 23° F. These data,

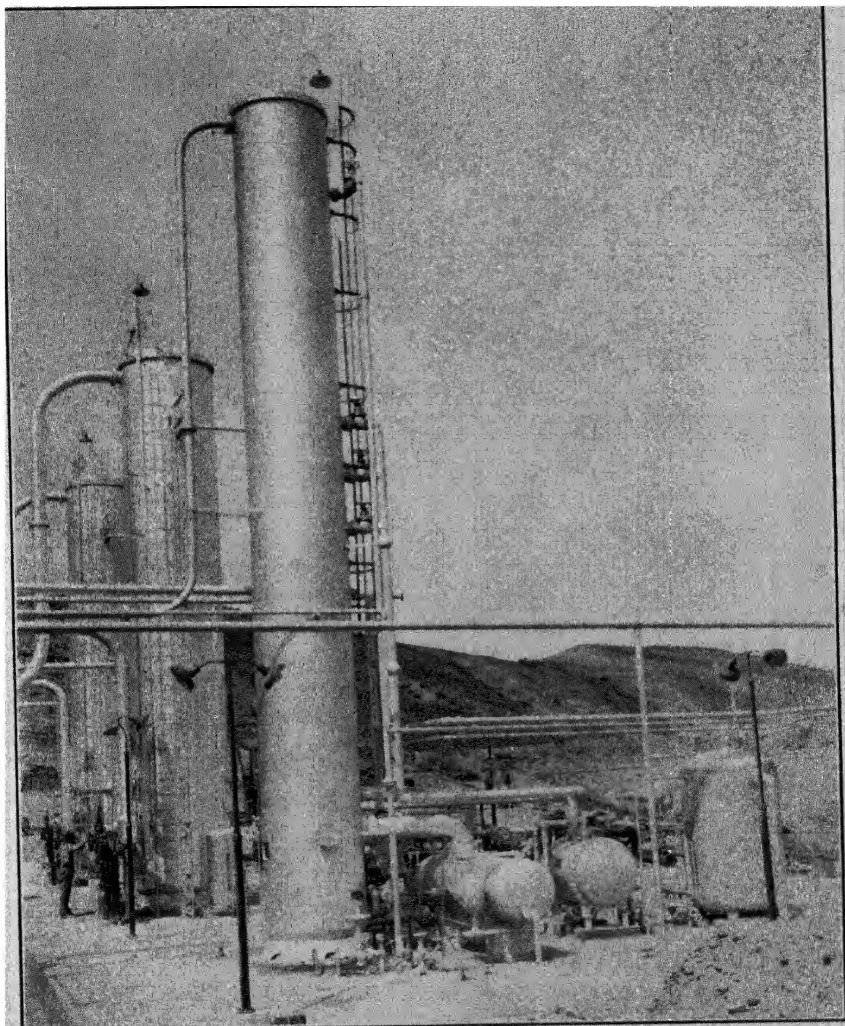


FIGURE 42. Aluminum-painted equipment in natural gasoline plant at Kettleman Hills, California. (Courtesy of Foster-Wheeler Corporation.)

together with Bureau of Mines Technical Paper No. 319 (1923) by J. H. Wiggins, indirectly afford a comparison of white paint with aluminum paint.

Vapor temperatures measured in tanks in the Pennsylvania field under somewhat cooler conditions than those in the Mid-Continent field showed the following average daily maximum variations in August (same time as above): black, 27° F.; red, 25° F.; white, 18° F. The aluminum tank, according to Schmidt's report, showed an average daily maximum fluctuation in temperature which was 9° F. less than in the case of the black paint. In the other series of tests reported by Wiggins the fluctuation in the white tank was also 9° F. less than that in the black tank, indicating approximately the same temperature efficiency from that standpoint for the white and aluminum painted tanks. No other data on full size tanks with white finish have been found, although Nelson and Jamieson have observed a temperature advantage for a chalking white paint in laboratory tests made on 5-gallon cans.²⁰

Schmidt and Wilhelm²² have also made an investigation of the reduction of evaporation losses in gasoline bulk storage station tanks located in the Kansas City territory. In addition to determining the value of aluminum paint in comparison with red paint, they included a

TABLE 8.

RESULTS OF COMPARATIVE TESTS ON FOUR 12,000-GALLON HORIZONTAL GASOLINE STORAGE TANKS, FROM MAY 29TH TO OCTOBER 15TH, 1930.

U. S. Bureau of Mines—Report of Investigations 3138.

Description of Data	Tank A*	Tank B	Tank C	Tank D
	Protected with Insulated Housing	Covered with Aluminum Foil	Painted Red	Painted with Aluminum Paint
Evaporation loss—gallons	112	170	284	187
“ —per cent. . . .	1.40	2.12	3.54	2.34
Daily Temperature Variation—°F. June	22.3	28.2	49.8	33.1
July	24.3	31.0	53.8	34.9
August	23.6	32.9	55.4	37.0
September	20.9	30.0	45.1	33.6
October	17.0	26.0	....	28.8

* Protected with an insulated housing consisting of roof and sides of corrugated sheet of asbestos fiber and cement, spaced at a minimum of 11 inches from the steel storage tank which was painted white.

test with an aluminum foil-coated tank and also included a tank that had an insulated housing or shed built over it, with an air space between the asbestos board insulation and the steel tank. A summary of some of their data is given in Table 8. While naturally the insulated shed

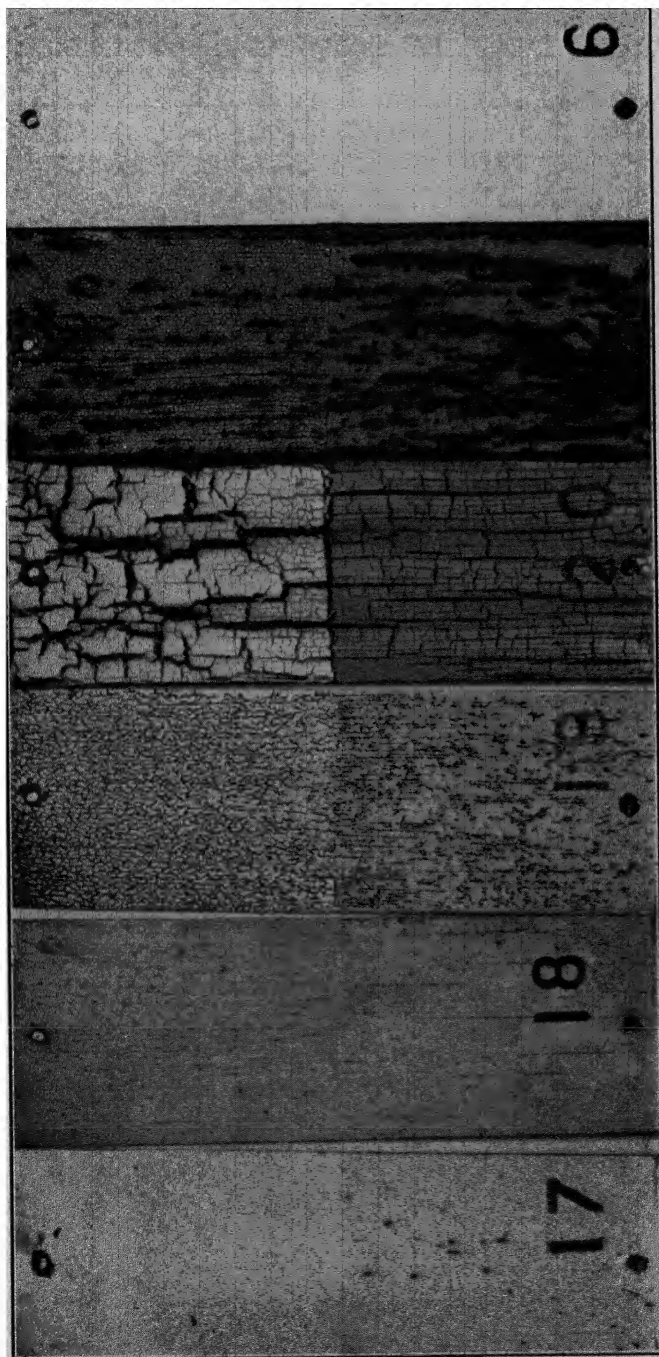


FIGURE 43. Durability of aluminum paint in comparison with other light colored paints as top coats; panel No. 17, titanox-zinc oxide; No. 18, gray titanox; No. 19, white lead-zinc oxide-inert; No. 20, white lead; No. 21, lithopone-zinc oxide-inert; No. 6, aluminum paint. Photograph made after 18 months' exposure at Houston, Texas.

was more efficient, it was more expensive than a coat of aluminum paint, which was quite effective. The maximum temperatures were reached in August, when the red tank recorded a temperature of 150° F. and the aluminum painted tank was about 22° F. cooler. The tanks were equipped with a pressure relief valve operating at 2-oz. pressure. Another aluminum painted tank with a relief valve operating at 5 pounds' pressure lost only 118 gallons of gasoline during the test period as compared with 187 gallons lost by the tank with the relief valve operating at 2-oz. pressure.

Gill, Rogers and McGary¹¹ have recommended the use of aluminum foil for protecting tanks against corrosion and for reducing evaporation losses. The tank is first given a coating of adhesive and the foil then applied much like wall paper. The high reflectivity of the foil makes it very effective from the thermal standpoint, but it is naturally more expensive than aluminum paint. Some efficiency comparisons between foil, aluminum paint and black paint are given in the references.

In order to compare the protective properties of aluminum paint and other light colored paints suggested for use on oil tanks, a series of exposure tests was made at Houston, Texas. Twenty-one steel panels were all primed with an inhibitive red oxide paint; 16 of the panels were then coated with various aluminum paints, and 5 with white paints of different types, one coat being applied to the bottom half of the panel and two coats to the top half. These panels were exposed for 18 months, facing south at an angle of 45°. When examined after this exposure, all of the aluminum painted panels were in excellent condition and, in general, were quite bright; they had been but slightly affected by the strong southern sun. The white and gray paints showed a substantial loss of protecting power, and all but the Titanox paint showed a very decided loss in reflectivity. Six of these panels after the 18-month exposure period are shown in Figure 43. Panel No. 6, which was protected with aluminum paint, seemed to be in almost perfect condition. Panel No. 17, which had the top coats of Titanox paint, maintained a reasonably bright surface, but the paint coating was obviously inferior in protecting power to the aluminum paint. Where the brightest possible surface is desired, a very hard-drying aluminum paint with a tendency to chalk, gives the best results. Aluminum paste pigment because of its brightness can be employed advantageously.

Aluminum Paint on Structures.

Aluminum paint has found practical use on other structures than oil tanks for the purpose of reducing interior temperatures. For example, La Motte¹⁵ has shown how aluminum paint can be effectively used in painting sheet iron magazines used for the storage of explosives. High temperatures cause the deterioration of explosives and it is very desirable to keep the interior temperature of these magazines as low and uniform as possible. Careful comparisons with black and aluminum

painted magazines showed that the interior temperature of the latter was as much as 14° F. lower at certain times of the day. Table 9, taken from this article, shows the observed temperatures inside and out of these magazines, both with the black and aluminum surfaces.

TABLE 9.
TEMPERATURES FOR MAGAZINES NOS. 1 AND 2.

Time	Temperature (°F.) outside Magazine in Sunlight		Temperature (°F.) outside Magazine in Shade		Temperature (°F.) inside Magazine	
	No. 2 <i>Black</i>	No. 1 <i>Aluminum</i>	No. 2 <i>Black</i>	No. 1 <i>Aluminum</i>	No. 2 <i>Black</i>	No. 1 <i>Aluminum</i>
July 17th						
5:30 A.M.	...	...	66	66	66	66
2:30 P.M.	108	108	94	94	108	94
5:10 P.M.	106	106	94	94	106	92

Hukill¹² found that the aluminum and yellow paints he tested were about equally efficient in reducing the surface temperature of insulated refrigerator cars. They were somewhat less effective than white and substantially more effective than red. No information is given regarding the composition of the aluminum paint used or its brightness. When the car was in motion, the heat carried away by the air currents reduced the surface temperature rise by about one-half. Unfortunately, soot and dirt collecting on the surface while in service increase the heat absorption, particularly in the case of the light colored paints. Hukill estimates for the summer months that a red roof on a refrigerator car in transit 75 per cent of the time would show an average temperature difference between surface and air of about 9° to 10° F. For side walls with yellow paint, the average difference would be 1° to 3° F., and for the end and floor surfaces, the surface temperature is probably very close to that of the air. If the roof was painted with white paints and it did not become soiled with dust, soot, etc., the average surface temperature rise might be as low as 5° F. Aluminum paint is recommended for the inside surfaces of the car to reduce heat transfer to the interior by radiation.

Carl G. F. Zobel²⁸ found that the average heat flow through a slate roof was reduced 38 per cent by dusting on aluminum bronze powder without any binder. While this is not a practical procedure, it is an interesting experimental result.

Emissivity.

A property closely related to the reflectivity of aluminum is its emissivity or radiating power. Like other metals, aluminum has a low emissivity and aluminum paint shares this characteristic, although not

quite to the same degree. The available evidence indicates that the emissivity of aluminum paint at temperatures of 40° C. (104° F.) is only about 30 per cent of that of a "black body," the theoretically perfect radiator.

Reflection, radiation, conduction and convection are the important factors in the heating and cooling of bodies. Reflection has already been considered. Conduction is not in general affected by the character of the surface, whether painted or not, and the effect of paint on convection is usually a secondary one. The difference between heat transfer by convection and by radiation can be illustrated by the common steam radiator. If the hand is held above the hot radiator, one feels the warm air currents ascending which are transferring heat from the radiator by convection. However, if the hand is held at some little distance from the side, the heat received is mainly by radiation from the heated surface. This radiated heat always travels in straight lines, but air convection currents usually pursue an irregular course.

The heat radiated by a body is relatively low at ordinary temperatures, say up to the boiling point of water. However, the loss of heat by radiation is proportional to the fourth power of the absolute temperature, and with increasing temperature it quickly becomes a dominating factor in heat transfer, since the heat loss by convection increases at a much slower rate. Just as the reflectivity of a substance may vary with the character or wave length of the incident light, so the emissivity of a body varies with the temperature or wave length at which it is radiating. The reflectivity of aluminum, and of aluminum paint, is greater for infra-red or the long heat waves than for visible light or energy. The radiation from bodies at and near room temperatures is mostly in the infra-red region; the emissivity of aluminum paint at such temperatures is correspondingly low.

Coblentz and Hughes,³ of the National Bureau of Standards, have made a study of paints for decreasing or increasing heat radiation from surfaces. They have found aluminum paint to have an emissivity (at atmospheric temperature or thereabouts) about 30 per cent that of white lead paint. The white paint had as high an emissivity (within 4 per cent) as that of a lampblack paint. Aluminum paint, suitably formulated, can be used on surfaces which are heated to temperatures up to a dull red heat and its effect in reducing heat losses at such temperatures is very substantial.

The emissivities of several types of aluminum paint and powder-coated surfaces, as measured by C. S. Taylor, are given in Table 9. These measurements were made with the radiating surfaces at a temperature of 100° F. The apparatus was calibrated with bright rolled aluminum foil, assuming for this foil an emissivity of 5 per cent on the basis of tests recorded in the literature. According to the data of Table 9, aluminum paint applied over metal foil seems to have a slightly higher emissivity than when applied to paper. This is probably con-

nected with absorption of the vehicle by the paper, giving a more metallic surface to the paint film when applied over paper. In the case of the papers coated with flitter, the paper was first given a coating of adhesive, the aluminum flitter dusted on and the paper then calendered, to insure good contact between the flitter and the adhesive. Flitter is a very coarse mesh aluminum powder and gives a very brilliant metallic surface, as is evidenced by the relatively low emissivity. Paper and other sheet materials coated in this way with aluminum flitter will find some use for insulation purposes because of the low emissivity of the surface.

TABLE 9.
EMISSION OF SURFACES COATED WITH ALUMINUM PAINT AND POWDER.
According to C. S. Taylor—Aluminum Research Laboratories.

Character of Surface	Emissivity at 100° F. per cent
Metal foil spray-painted with Extra Fine Lining Powder.....	33
Paper spray-painted with Extra Fine Lining Powder.....	31
Metal foil spray-painted with Standard Varnish Powder.....	33
Paper spray-painted with Standard Varnish Powder.....	30
Metal foil spray-painted with standard aluminum paste in alkyd resin vehicle	28
Kraft paper, coated with adhesive and with aluminum flitter (18 mesh), calendered	21
Asbestos paper, coated with adhesive and with aluminum flitter, calen- dered	24
Aluminum foil rolled on polished rolls	5
(Value of 5 per cent assumed for calibration of emissivity appa- ratus.)	

Finck,⁸ in studying the mechanics of the heat flow through fibrous materials used aluminum powder to determine the effect of radiation. Kapok, for example, very loosely packed to a density of 0.003 g. per cm.,³ had a conductivity of 0.540 milliwatts cm.⁻¹ deg.⁻¹ C. When, however, dry aluminum powder was dusted throughout its mass and the fibers coated with the bright aluminum flakes, the heat transfer by radiation was so reduced that the thermal conductivity was 17 per cent lower (0.455). When the kapok was more tightly packed, a condition more nearly that used in practice (density of 0.016), the aluminum powder had a negligible effect upon conductivity. Similar results were observed with other fibers.

Aluminum Paint on Furnaces.

As an illustration, the test given by the author in an article entitled, "Aluminum Paint—A Heat Saver," may be cited.⁶

A series of tests was made upon an electric furnace of the laboratory type used for heating tubes in combustion analyses. As originally made, it was painted black with white composition-board ends. When operated in this condition, it was found by a number of observations sufficient to determine average performance, that with a power input of about 630 watts (at 110 volts) the center of the furnace reached a temperature of 954° C. (1749° F.). After applying a coat of aluminum paint to the exterior, it was found that with exactly the same power input, the temperature reached was just 22° C. (40° F.) higher, namely, 976° C. (1,789° F.). Obviously, the original temperature could have been maintained with a smaller power input with the aluminum painted surface. With furnaces operating at a higher temperature, the gain would be even greater. In many cases the upward extension of the attainable temperature, which can be reached by the use of aluminum paint, is particularly desirable. If a higher temperature is not necessary or desired, the operating temperature can be maintained with a smaller power input than when an ordinary brick or iron surface is employed.

An additional important advantage of the aluminum paint on furnaces is that it makes the neighborhood of the furnaces more comfortable for the workmen, since they receive less heat by radiation. In one particular case, two identical furnaces stood about 12 feet apart. One was finished with aluminum paint and the other with black paint. Standing between and equidistant from the furnaces, one could not help but notice the greater amount of radiant heat coming from the black furnace.

Of course, the surface of the aluminum painted furnace is actually hotter than if it were not so painted, because a larger proportion of the heat must be carried away by convection; the aluminum paint dams up the heat, to use a crude analogy. In the case of the laboratory furnace previously cited, a particular point on the surface was at a temperature of 168° C. (334° F.) when painted black, and 224° C. (435° F.) when coated with aluminum paint. With a higher surface temperature, a greater amount of heat can be dissipated by convection.

Many are making practical use of the low emissivity of aluminum paint on furnaces of all types and sizes from the laboratory furnaces just described to large fuel-fired and electric furnaces. An electric furnace installed at New Kensington was received from the maker with a coat of black paint. After installation it was given a coat of aluminum paint; on its initial tests it did enough better than the average performance of this type of furnace to leave the maker puzzled as to the improvement in efficiency until told about the effect of aluminum paint.

A test on a small boiler shell (3.3 sq. ft. of surface) heated by a 5000-watt electric resistance heater gives an interesting comparison of the heat loss from various surface finishes.² With a temperature of 150° F. inside the shell and assuming the energy input required to maintain this temperature to be 100 when the exterior surface was bare, the relative energy required with a $\frac{1}{4}$ -inch coat of asbestos plaster on the out-

side of the shell was 89; with aluminum paint on the shell, 78; with a coat of sprayed metal, 72, and with 2 inches of asbestos plaster, 28. At a temperature of 300° F., the relative energy requirements were as follows: Bare iron, 100; $\frac{1}{4}$ -inch asbestos, 89; aluminum paint, 81; aluminum metal, 71; 2-inch asbestos, 27. The aluminum paint was evidently not of the right composition, for at temperatures of 500° F. and higher, it discolored and blistered. Aluminum paints are available which stand these high temperature conditions satisfactorily.

The selection of the proper type of vehicle and its application are very important points in the painting of surfaces which are to be heated. Where the surface is to be heated up to temperatures of about 200° C. (392° F.), almost any varnish vehicle will serve satisfactorily. It should preferably be of rather thin consistency and should be diluted, if necessary, to give a freely flowing paint. Where the surface reaches temperatures of about 250° C. to 400° C. (482° F. to 752° F.), the gloss oil or spirit varnish type of vehicle usually works better. Some of the very best aluminum paints available for use on surfaces to be heated, are made with synthetic resin vehicles. These vehicles are usually quite thin in consistency, and contain a large proportion of volatile material. Bakelite lacquer is suitable for this purpose. At such temperatures as those mentioned the vehicle may burn out, but if the paint has been applied to a clean iron surface, the flake aluminum remains closely adherent to it. Some component of the vehicle appears to flux the metallic powder to the iron surface in such a way as to give excellent adherence even though the organic material burns out practically completely. With a suitable vehicle, the adherence is so remarkable as to give the impression that the metallic aluminum had been alloyed with the iron, although microscopic examination shows no evidence of alloying. The aluminum flakes retain their characteristic color even up to the melting point of aluminum. It is essential, however, that the paint be applied to a clean iron surface, free from paint, rust and grease, and that it be allowed to dry thoroughly before being heated. These vehicles are not particularly weather resistant and should not be expected to stand both high temperatures and weather exposure.

Aluminum Paint on Radiators.

The use of aluminum paint on house heating radiators has been a much debated subject and some rather extreme views have been expressed. A steam-heated radiator operates at a low enough temperature so that convection is the important factor in transferring heat to the room. For this reason, even though the emissivity of aluminum paint be but 30 per cent of that of a black or other good radiating paint, the rate of heat dissipation from the radiator is decreased only about 10 to 15 per cent thereby. Tests carried out in the Research Laboratories of the Aluminum Company of America on a 2-column, 4-section radiator of the usual type under standard operating conditions showed a reduction

in heat dissipation of 13.2 per cent with an aluminum painted surface in comparison with the rusty iron surface, or 11.1 per cent in comparison with the surface coated with white paint. It should be noted in this connection that the aluminum painted radiator runs with a hotter surface, which increases the air convection losses. This is desirable, since it is the warm air from the radiator that gives a feeling of comfort. The radiated heat travels largely to walls, furniture and other objects in a direct line. When desired, the emissivity of aluminum paint can be markedly increased by tinting with a non-metallic pigment as described on page 91.

The fact that aluminum paint decreases the heat dissipation by radiation might even be urged as an advantage and sufficient justification for the very long-continued use of aluminum paint on radiators. R. V. Frost,⁹ who made an investigation of the "heating effect of radiators," concluded that much of the heat dissipated by radiation from a radiator is in effect lost. Where a radiator is placed against an outside wall, as is commonly the case, heat radiated from the back of the radiator is largely wasted. Heat radiated from the top and bottom of the radiator is also ineffectively used, as it goes to heat ceiling and floor. Frost cites the case of a cast-iron radiator which was compared with a fin-type radiator enclosed in a cabinet, which had the effect of cutting off radiation from the sides of the radiator. Although the cast-iron radiator condensed 20 per cent more steam than the cabinet-enclosed radiator, the latter produced the same average temperature in the room and with a better temperature distribution, that is to say, more uniform temperature conditions from floor to breathing line.

Coblentz and Hughes, in the article previously referred to, have suggested the use of aluminum paint on the inside of auto tops, tents, metal roofs, balloon hangars, observatories and other structures which it is desired to keep from heating up in the sunlight. For the top surface they recommend a white paint with a higher reflectivity than aluminum paint, in order to secure maximum reflection and emission. In actual practice, the superior durability of aluminum paint, and the fact that it gives maximum reflectivity with fewer coats, are points to be considered.

Paints for Transformers.

In the painting of self-cooled transformers there are a variety of factors which determine the net thermal effect. In operation, heat is being generated within the transformer windings and must be dissipated from the surface of the transformer tank. Furthermore, when the transformer is outdoors in sunshine it will be absorbing solar energy. In order to settle some of the disputed points regarding the effect of the color of paint on the temperatures of self-cooled transformers under service conditions, Messrs. L. Wetherill and V. M. Montsinger²⁶ have carried out a series of tests. For tanks which are situated indoors or *in shade*, their conclusions are as follows:

"1. The temperature rise of a transformer in a tank painted with a non-metallic paint is practically independent of the color.

2. Metallic paints radiate less heat than non-metallic paints and may cause a transformer to overheat.

3. A plain aluminum painted tank will run approximately 30 per cent higher temperature rise* than if painted with a non-metallic paint.

4. Thirty per cent represents the maximum increase of temperature rise caused by painting a tank with aluminum instead of a non-metallic paint. If a plain tank is finished with a surface having a lower emissivity than aluminum the temperature increase will naturally be more than 30 per cent, increasing to about 75 per cent* where the emissivity is very low, such as for polished silver, nickel, etc.

5. As the surface of a tank becomes more and more convoluted (with tubes and externally connected radiators) the effect of a metallic paint in increasing the temperature rise becomes less and less, in extreme cases getting as low as 7 per cent.*"

Other tests have shown, however, that the emissivity of the aluminum painted surface can be raised substantially to that of non-metallic paints by the application of a coat of clear varnish or lacquer over the aluminum paint. In the case, therefore, of an aluminum painted transformer where the temperature rise is considered excessive, it can be reduced by the application of a coat of varnish.

In the case of transformers operating *in sunshine*, Wetherill and Montsinger state their conclusions as follows:

"1. The improvement resulting from using special paint on self-cooled transformer tanks either plain or with convoluted surfaces is in service very small, hardly enough to be worth considering. Even under the most favorable conditions (white lead paint, smooth tank surface, and a hot sunny day), the gain is not more than 2 degrees C. average during a 24-hour period and in some cases less than 2 degrees C.

2. The repainting of transformer tanks in the field for operation in the warmer sections of the country should be based upon the consideration of durability and appearance rather than upon color."

Aluminum paint has been used on transformers located outdoors and with very satisfactory results. The durability and clean, bright appearance of aluminum paint, including especially the ease with which oil stains may be washed from it, make it a very practical paint for this purpose.

* Refers to oil rise. The winding rise over room will be increased the same number of degrees as the oil rise is increased.

Opacity.

A marked characteristic of a metal is its perfect opacity. It is true that exceptionally thin metal films have been prepared which show some light transmission, but for practical purposes the flakes of aluminum powder are completely opaque to light. An easy way to test this point is to paint a coat of aluminum paint on glass and hold it before the filament of an electric light. If complete covering has been secured, the filament will be entirely obscured. In contrast with this, a similar test of five

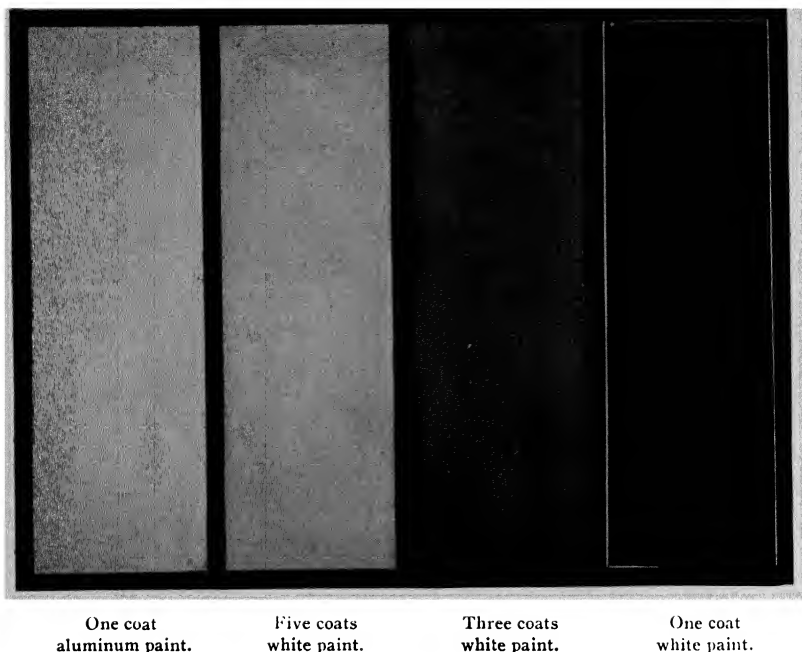


FIGURE 44. Comparative opacity of aluminum paint and white paint as shown by exposing photographic paper through the respective paint films; the transparency of the paint films and consequently the depth of exposure of the paper decreases from right to left of the picture.

coats of white paint on glass showed very substantial light transmission. It is because of the complete opacity of the aluminum flakes that the usual methods of determining the hiding power of a paint are inapplicable to aluminum paint.

The high opacity of aluminum paint is illustrated by Fig. 44. The figure is reproduced from a print which was made by simultaneously exposing photographic printing paper through a series of paint films. The area of paper beneath the aluminum paint film was pure white, showing no exposure and hence no light transmission. The increase in opacity of the white paint films with increasing number of coats is apparent, but

there is substantial light transmission even with five coats of white paint. A commercial titanox-zinc oxide paint, which has about the best hiding power of any of the white paints, was used in this test.

Aluminum paint will hide completely in one coat, provided a well leafed uniform coating is secured. For most practical purposes, the ideal of a well leafed and uniform coating of high opacity can be secured by mixing aluminum paste in a vehicle of the proper character and consistency and using the mixed paint while it leafs readily. The opacity of an aluminum paint film is well demonstrated by the photographic print made from a flow-out as shown in Fig. 13 on page 43. Its remarkable hiding power, coupled with its substantial reflecting power, make aluminum paint very useful for interior walls and surfaces where lighting efficiency is desired, and where the advantage of using only one, or at most, two coats of paint is important.

The hiding power of a paint film is not directly proportional to the thickness of the film. The curve expressing the relation of thickness of film and hiding power is of hyperbolic or logarithmic form. In the case of white and tinted paints, the first coat is very much more effective than the second coat, and the efficiency of succeeding coats decreases rapidly. It is important, therefore, to use a pigment of high intrinsic opacity so as to secure maximum hiding in the first coat. An aluminum paint with a varnish base was applied over a black iron panel; with one coat the reflectivity of the surface was 69 per cent, and with two coats the reflectivity was 70 per cent; substantially maximum reflectivity was obtained with the first coat. A standard white lead-zinc oxide paint applied in the same way over the iron panel gave a reflectivity of 60 per cent in one coat and 66 per cent in two coats. Similarly, titanox paint with somewhat greater hiding power gave a reflectivity of 70 per cent in one coat and 75 per cent in two coats. When applied to dark surfaces, much thicker films of white paint must be applied to overcome the inferior hiding properties of the white paint and develop its maximum reflectivity than is the case with aluminum paint. Usually three or four coats of white paint are required to approximate its maximum reflecting power.

From the theoretical standpoint, the opacity of aluminum powder is the chief factor in explaining the durability of aluminum paint. It has long been known from a practical standpoint that light is a very important factor in the deterioration of paint; the special significance of ultraviolet light as a factor in paint destruction, is now well recognized. Aluminum powder is equally opaque to visible and ultraviolet light.

It is logical from this viewpoint that the adulteration of aluminum powder with material of substantial transparency, such as mica, should lower the durability of paint made with it. Experience proves this to be the case. Test panels of mild steel were painted with one and two coats of paint made with spar varnish and aluminum powder (2 pounds of powder per gallon of varnish). The powder used in three of the

paints contained 10, 25 and 50 per cent, respectively, of ground mica, and one panel was painted with pure mica suspended in spar varnish. Such adulteration may be very deceptive, because substantial amounts of mica can be mixed with aluminum powder without changing its general appearance. On the weather exposure tests, the 100 per cent mica panel showed rusting after a relatively short period of exposure, and all the panels containing mica began to fail before the panel coated with pure aluminum paint; the order of failure corresponded with the mica content.

Prevention of "Bleeding."

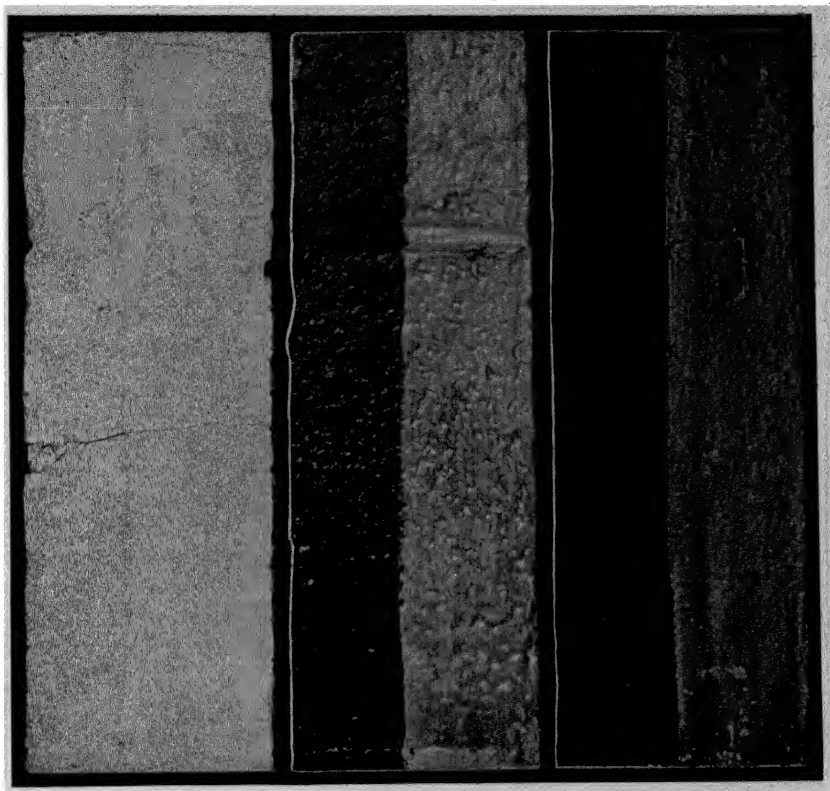
Painting over oil stains, bituminous paints and other colored oil-soluble coatings presents the problem of preventing "bleeding" through, as it is called, of the ground coats. Frequently, for example, the occasion arises for refinishing mahogany-stained woodwork in white or light colored enamel. If the enamel is applied directly, the oil stain will gradually dissolve in it and work through and stain the surface. A ground coat of aluminum paint over the stain will often prevent the bleeding through, and top coats of white paint or enamel may be applied on top of the aluminum. If the stain has been freshly applied it will be necessary to wash the surface with a solvent (and dry) to remove as much stain as possible before applying the aluminum paint. In such cases it may also require two coats of aluminum paint to stop bleeding.

Another such case is painting over bituminous paints, and here also aluminum paint can be applied satisfactorily. With ordinary light colored paints, the bituminous material is almost certain to dissolve and stain the surface. The high impermeability of aluminum paint films, as shown by the moisture-resistance test, seems to be operative against stains and the like. However, not all cases are alike, and certain guiding principles should be followed in selecting the aluminum paint. In general, the softer the bituminous coating or the more penetrating the stain, the quicker drying should be the aluminum paint vehicle, and the more impervious the film it produces. Linseed oil, for example, which forms a slow-drying and soft film, is usually unsatisfactory as a vehicle for aluminum paint where prevention of bleeding is desired. Varnishes, on the other hand, will dry faster with less softening of the undercoats and are themselves less readily penetrated. With the addition of aluminum powder, the sealing effect is almost always complete.

The aluminum paints should be applied by spray, if possible, to avoid disturbing the bituminous undercoat, as sometimes happens when the paint is applied by brushing.

Five of the most commonly used bituminous paints were painted on sheet iron and allowed to dry for 14 days. They were then given top coats of aluminum paint made with spar varnish, gloss oil and bodied linseed oil as vehicles. The spar varnish was entirely satisfactory, but some staining occurred with the gloss oil, and still more with the bodied linseed oil. Similar panels were then placed on a steam-heated radiator

for several weeks. This is a severe test, because the heat tends to soften the bituminous film. Even under these conditions, no bleeding occurred through the aluminum paint made with spar varnish, except in the case of one very slow-drying coal-tar paint.



Panel No. 1.
Entire surface primed
with aluminum paint (var-
nish vehicle) with 1 top
coat white paint on right
half.

Panel No. 2.
Entire surface primed
with red lead paint with
1 top coat white paint on
right half.

Panel No. 3.
Entire surface primed
with zinc dust-zinc oxide
paint with 1 top coat
white paint on right half.

FIGURE 45. Paints for asphalt-coated corkboard.

The test was repeated, allowed three months' drying time for the bituminous paints before applying the top coats of aluminum paint. The very slow-drying asphalt stack paint, to a slight extent, bled through the aluminum paint made with gloss oil and with bodied linseed oil. Good results were obtained in all other cases.

A very important and practical use of aluminum paint is in painting refrigeration installations. One of the common insulating materials is corkboard coated with mastic or bituminous waterproofing material.

Aluminum paint apparently is one of the few light colored paints which can be applied to such surfaces without staining.

In Figure 45 are shown the results of painting asphalt-coated cork-board with various primers which have been recommended for the purpose. The panels from left to right were primed with aluminum paint (varnish base), red lead paint, and zinc dust-zinc oxide paint. The right half of each panel was then given a coat of white lead-zinc oxide paint. The aluminum primer prevented any bleeding whatever, of the asphalt; moreover, one coat of aluminum paint gave about as bright a surface as the aluminum paint with a top coat of white. The red lead was somewhat less satisfactory as a primer, and the zinc dust primer permitted a very objectionable staining of the top coat of white by the asphalt. A quick-drying spar varnish should be used as the vehicle. The aluminum paint is also resistant to ammonia fumes and is a good all-round protective paint. The thermal properties of aluminum paint may also be used to advantage on insulating coatings.

Painting Over Creosoted Wood.

A special problem in the prevention of bleeding is presented by creosote-impregnated wood. A substantial quantity of creosote may be held in the impregnated wood so that an appreciable fluid pressure will be exerted against parts of any superimposed paint film, particularly on hot, sunny days. Creosote also has a high solvent action on paint, oil, varnish and lacquer films, which is conducive to bleeding. Creosote-impregnated poles and posts are extensively used along highways and it is imperative to increase their visibility by giving them a light colored finish. W. P. Arnold, of The Wood Preserving Corporation, has investigated the problem intensively and has reached a number of practical conclusions.²⁵ In the first place, the wood treatment can be carried out so as to leave a surface better adapted to subsequent painting. The wood should also be seasoned after impregnation and before painting. The following directions should be observed to secure the best results in the painting of round poles or guard-rail posts:

"The material shall have been treated with a maximum of 8 lbs. per cu. ft. of Grade No. 1 creosote, containing less than 25 per cent residue above 355° C.

The seasoning period in the *South* after treatment shall in no case be less than three months of summer weather and, if treatment is made in the winter, the seasoning shall extend through at least one month of the first warm weather in the spring. The seasoning period in the *North* after treatment shall in no case be less than five months of summer weather and if treatment is made in the autumn or winter, the seasoning shall extend at least through the month of May."

With regard to the paint itself, they state:

"Since creosote has such a high solvent property on ordinary pigmented paints, it has been impossible to obtain satisfactory results with white or light colored paints. Satisfactory results have been obtained only with aluminum paint, which forms a metallic layer of the aluminum particles on the surface of the paint

FIGURE 46. Creosoted pole in California, two years after coating with aluminum paint.



film. The layer of metal particles makes it difficult for the creosote to bleed through. However, the vehicle with which the aluminum powder is mixed must also contribute to the sealing of the creosote.

In an attempt to find a satisfactory paint for creosoted wood, we have tested over one hundred mixtures in coöperation with paint companies and other organizations. In making these tests, two methods were used:

1. Application of a sealer not containing aluminum powder, followed by an aluminum paint.

2. One-coat application of aluminum paint direct.

A large variety of paints were used as sealers and as vehicles for aluminum powder, including the following general types, of which many variations and combinations were used:

- | | |
|--------------------------------------|-------------------|
| 1. Asphalt base | 7. Shellac |
| 2. Tar base | 8. Varnishes |
| 3. Asphalt emulsion | 9. Water paints |
| 4. Synthetic resins (Bakelite, etc.) | 10. Rubber base |
| 5. Synthetic resin emulsion | 11. Fish oil |
| 6. Lacquers | 12. Linseed oil." |

Of all the combinations tested, one particular tar-base vehicle aluminum paint and a certain short oil varnish-base aluminum paint gave the best results.

Before attempting to paint creosoted lumber, the surface should be cleaned free of all adhering material, such as dirt, oil or tar, which may have exuded from cracks or pores in the wood. This is best accomplished by wire-brushing. While paint may be applied by either brush or spray, the latter method is advantageous, since it permits the uneven surface of a pole to be more uniformly coated without working up creosote from the wood. When applied by brushing, it should be done with as few strokes as possible. The aluminum paint should also leaf well, which condition is best obtained by freshly mixing the aluminum powder and vehicle just before using.

Electrical Conductivity.

It might be considered, since aluminum itself is such a good conductor of electricity, that aluminum powder would be electrically conducting. The presence, however, of the film of polishing agent on each particle, as well as a film of oxide, quite efficiently insulates the powder. A column of aluminum bronze powder about 2 mm. in thickness and 4 mm. in diameter was found to have a resistance greater than 10,000,000 ohms. Aluminum paint films, therefore, with the additional insulation afforded by the vehicle, may be considered as non-conducting under some conditions. However, at some voltages—say above 100 to 300 volts—the paint film may break down and permit the current to pass by disruptive discharge. For this reason aluminum paint should not be put on surfaces which are supposed to be insulating in character. It is likewise true that no paint should be applied to high voltage insulators.

In high voltage electrical condensers of the type using metal plates with glass dielectric, there is some corona loss at the edges of the metal plates. J. E. Mack found that the corona could be reduced and higher potentials reached if a narrow band (1 inch) of aluminum paint was applied on the glass next to the edges of the metal plates. Bundy and Pool¹ also tested the effect of aluminum paint made with celluloid lacquer, and with glyptal lacquer. When dry, neither of these paints

showed any conductivity for potential gradients up to about 20 volts per centimeter. Under a sufficiently high potential gradient, however, the paints broke down and became conducting. The conductivities were found to be of the order of 5.9×10^{-4} and 4.5×10^{-4} reciprocal ohms per centimeter square for the aluminum powder in glyptal lacquer and celluloid lacquer, respectively. They observed that, after such breakdown, the conductivity of the aluminum paints decreased with time. On condensers the aluminum powder in glyptal lacquer showed the most satisfactory performance.

A peculiar case of blistering of aluminum paint was observed on only one part of the exterior of a small frame building housing a radio broadcasting station in the south. It was apparently not traceable to any of the usual causes of paint failure. Suspicion, of course, fell on the high frequency currents generated in the transmitter and their heating effect upon metals within the electrical field. Subsequently, aluminum-painted wood panels were exposed close to powerful high frequency electromagnetic fields,—in one case 980 kilocycles, and another 11,760 kilocycles, at a broadcasting station near Pittsburgh. The panels exposed to the higher frequency smoked and blistered within two or three minutes after exposure. The panels exposed to the 980 kilocycles field showed blistering after several days' exposure. Linkage of the high frequency field with the conducting metal flakes of aluminum created eddy currents with their accompanying heating effect. Where the absorbed energy was sufficient, blistering occurred over wood. On steel, the aluminum flakes would be protected because of the electromagnetic shielding action of the steel; the higher thermal conductivity of the steel would also be a factor.

Permeability to Moisture.

The permeability of a paint film to moisture, or more particularly, its resistance to penetration by moisture, is one of its fundamental properties which is of great importance in many applications. Paint films are generally considered water-proof and that is true, at least when new, in the sense that they readily shed liquid water or withstand brief immersion in water. Their resistance, however, to penetration by water vapor over extended periods may be either very high or low, depending upon the composition of the particular paint film and its age. Aluminum paint films are of particular interest because of their high resistance to penetration by moisture, either liquid or water vapor.

While water may, of course, pass through holes or capillary spaces in a paint film, such defects are usually at a minimum in a good paint coating. The more general way in which moisture penetrates a film is by diffusion; moisture dissolving in the vehicle, diffuses through the paint film, and evaporates from the other side or is absorbed there. This process is quite analogous to that by which moisture and other gases pass through rubber films.⁵

Wray and Van Vorst²⁷ have investigated some of the factors determining moisture resistance of paint films. They have described their method as follows:

"The paint films were prepared by spinning on amalgamated tinplate panels, using the spinning device described by Gardner. In each case 25 cc. of paint were placed in the center of the panel which was then revolved at a speed of 300 r. p. m. After the paints were dry, disks 10.5 cm. in diameter were stripped from each panel and sealed with a special wax composition to the tops of shallow Petri dishes partially filled with activated alumina, which is an effective moisture absorbent. (Fig. 47). The dishes were carefully weighed and placed in a humidity cabinet automatically maintained at 95 per cent humidity at 27°C (80°F). They were re-weighed at intervals of 48 hours to determine the amount of moisture absorbed by the activated alumina, and hence



FIGURE 47. Assembly for measuring the permeability of a paint film. Completely assembled unit on left; right, paint film stripped back, showing wax seal and Petri dish containing activated alumina.

the rate of moisture penetration through the film. The permeability of the coatings is expressed as milligrams of moisture diffusing through one square centimeter of film per hour. In comparing data it is sometimes more convenient to use the reciprocal of the permeability, which may be called the impermeability, moisture resistance, or moisture impedance of the film."

Wray and Van Vorst found that the moisture impedance of a paint film was closely proportional to its thickness. For example, doubling the thickness of a paint film, other factors remaining constant, doubles its moisture impedance. Knowing this relation and the thickness of the paint film under examination, they could, by interpolation, calculate the moisture impedance of the paint film at a standard thickness of 0.001 inch per coat. These adjusted values of moisture impedance can be compared directly. In table 10 are given the results of a series of measurements on aluminum paint films with Standard Varnish and Standard Lining powders, in five different powder concentrations. The Standard

Varnish powder showed about 57 per cent through a 325-mesh screen and the Standard Lining powder showed about 81 per cent through a 325-mesh screen. Increasing the fineness of powder, and hence the number of flakes per pound, increased the moisture impedance, as did also increasing the percentage of powder incorporated in the paint vehicle. The moisture impedance was found to increase uniformly (linearly) with increase in the powder content with either grade of powder. In Table 11 are given another series of measurements of moisture impedance showing various grades of aluminum bronze powder and aluminum paste in films of one, two and three coats.

TABLE 10.

EFFECT OF VARYING POWDER FINENESS AND CONTENT ON MOISTURE IMPEDANCE OF ALUMINUM PAINT.

According to Wray and Van Vorst.
(One-coat films of aluminum paint made with varnish D.)

Pigment	Powder Content per Gallon of Vehicle	Moisture Impedance	
	Pounds	Observed	Interpolated**
Standard Varnish Powder	0.5	4.2	4.9
	1.0	5.0	5.7
	1.5	6.8	7.4
	2.0	10.8	9.6
	3.0	21.4	15.7
Standard Lining Powder.....	0.5	3.2	6.2
	1.0	4.6	7.2
	1.5	6.9	9.1
	2.0	10.0	11.9
	3.0	19.4	19.4
Varnish D* alone without powder.....	...	2.9	4.0

*Varnish D is an 80-gallon varnish with 49 per cent non-volatile content.

**Impedance value calculated for a film of 0.001 inch thickness.

Since moisture passes through a paint film by diffusion, the moisture resistance of the vehicle portion of the dry film is of importance. Linseed oil gives films of relatively low moisture resistance, while spar varnishes of the conventional type are substantially better in this respect. The moisture resistance of the film may, however, be still further increased by the use of varnishes made with some of the synthetic resins, such as the glycerol-phthalate or phenol-formaldehyde resins. With any given vehicle, the moisture resistance increases with increase in pigment concentration. It has been shown, moreover, by Wray and Van Vorst, that aluminum bronze powder is exceptionally effective in increasing the moisture resistance of the paint film.

TABLE 11.

MOISTURE IMPEDANCE OF ALUMINUM PAINT MADE WITH VARIOUS GRADES OF POWDER IN VARNISH D.

According to Wray and Van Vorst.
(80-gallon varnish with 49 per cent non-volatile content.)

Paint Coatings	Coats	Pigment Content		Moisture Impedance*	
		% by wt.	% by vol.	Observed	In'polated
Standard Varnish Grade	1	21.5	8.7	8.5	9.2
	2	21.5	8.7	18.	22.
	3	21.5	8.7	28.	34.
Standard Lining Grade..	1	21.5	8.7	10.	12.
	2	21.5	8.7	19.	25.
	3	21.5	8.7	26.	36.
Extra Fine Lining Grade	1	21.5	8.7	9.6	13.
	2	21.5	8.7	19.	27.
	3	21.5	8.7	26.	36.
Aluminum paste pigment No. 1	1	13.	4.9	5.0	7.8
	2	13.	4.9	9.3	17.
	3	13.	4.9	14.	24.
Aluminum paste pigment No. 2	1	14.	5.3	4.4	7.9
	2	14.	5.3	9.5	18.
	3	14.	5.3	13.	25.
Aluminum primer (Standard Varnish)+2 coats lead-zinc in oil...	3(Primer 21.5 (Top coat 66.0		8.7) 24.4)	14.	9.7
Aluminum primer (Standard Lining)+2 coats lead-zinc in oil...	3(Primer 21.5 (Top coat 66.0		8.7) 24.4)	17.	11.5
Aluminum primer (paste)+2 coats lead- zinc in oil.....	3(Primer 13. (Top coat 66.0		4.9) 24.4)	12.	8.3

* Interpolated impedance values calculated to a standard film thickness of 0.001".

TABLE 12.

EFFECT OF DIFFERENT PIGMENTS ON MOISTURE IMPEDANCE OF VARNISH A*.
According to Wray and Van Vorst.

Pigment	Pigment in Dried Film		Ratio of Moisture Impedances, Pigmented Film to Clear Films			
	% by wt.	% by vol.	1 coat	2 coats	3 coats	Average
Aluminum	36	16	5.0	7.3	7.8	6.7
Lithopone	74	37	4.5	4.8	5.1	4.8
White lead-zinc oxide (paste form).....	72	26	1.9	2.7	2.4	2.3

* Varnish A is an 80-gallon ester gum varnish; 51% non-volatile content.

In an aluminum paint film, the leafed layer of flake-like particles of aluminum powder at the surface offers an effective barrier against moisture penetration. Likewise, the flakes distributed throughout the film lie with their long axes more or less parallel to the surface, so that moisture passing through the vehicle must diffuse around and between these flat flakes of aluminum, and hence pursue a very long and circuitous course as compared with the short diffusion path through a paint film made with granular pigment.

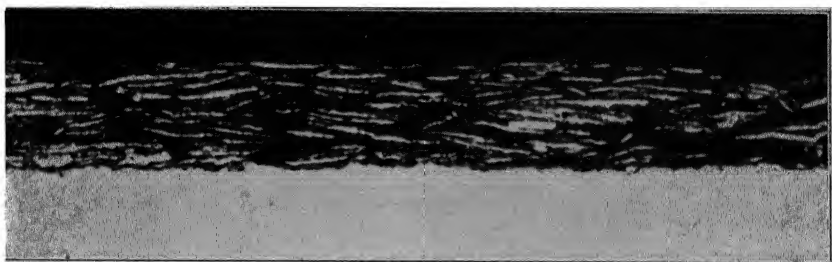


FIGURE 48. Cross-section of two-coat aluminum paint film (magnified 500 diameters) showing circuitous path for diffusion of moisture between and around flakes.

Table 12 shows the results of a comparison of several different pigments in the same vehicle.

Commenting on these figures, they state:

"Using the figures for the averages, the moisture impedance of this particular clear varnish is found to be increased about 40 per cent $[(6.70 \times 100)/16]$ for each volume per cent of aluminum bronze powder incorporated in the dried film. The moisture impedance is increased only about 13 per cent for each per cent of lithopone and 9 per cent for each per cent of white lead-zinc oxide pigment. The last figure is not quite comparable, however, for the lead pigment was added to the varnish in the form of a paste in linseed oil, and the moisture resistance of the varnish would be lowered somewhat by the added oil. The ratios of Table 12 will vary with different vehicles as well as with different pigments. Aluminum pigment in flake form is evidently much more efficient in moisture-proofing a paint film than is a granular pigment."

The assumption has been made frequently that the amount of moisture penetrating a paint film was proportional to the difference in concentrations of water vapor at the two faces of the paint film. Edwards and Wray have shown, however, that this linear relationship only holds below certain limits.⁷ Fig. 49 shows the relationship between the moisture penetrating an aluminum paint film and the relative humidity of the air on one side of the paint film with dry air in contact with the other

side. The relationship is linear up to a humidity of about 80 per cent at 80° F, but above this point the rate of penetration is greater than called for by the linear relationship. Another series of tests (same Figure) showed that the amount of moisture absorbed by the film followed the same relationship.

The same authors found the temperature coefficient of permeability to be small. The permeability decreases slightly with increase of temperature.

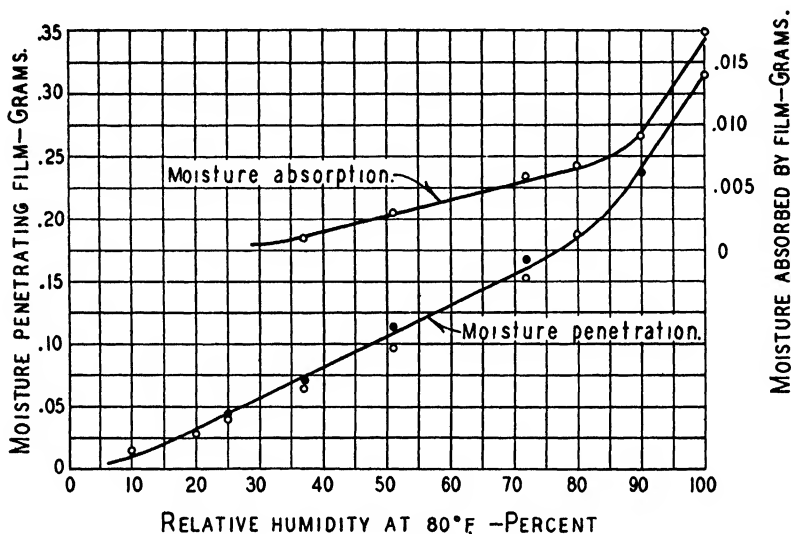


FIGURE 49. Relationship between moisture content of air and moisture absorption or moisture permeability of an aluminum paint film.

Baking or force-drying of paint films generally increases their hardness; it also increases the resistance to moisture penetration. The moisture impedance of aluminum paint films, for example, was about doubled by a suitable baking treatment.⁷

Effect of Aging on Permeability.

The moisture permeability of a paint film follows a typical cycle as it ages, just as do other physical properties, such as strength and distensibility. During the aging of a paint film, incident to weather exposure, the permeability may show little change for a short period, or perhaps a gradual decrease in permeability. In nearly every case, however, the permeability eventually shows a sharp decrease. This change appears to be associated with the marked hardening of the paint film which is commonly observed. Once the low point in permeability is reached, there will be an increase which will be fast or slow, depending on the vehicle and pigment employed, as well as the exposure conditions. The

character of these changes is well illustrated by the data of Table 13, which show the moisture impedance of a series of aluminum paints made with synthetic resin vehicles, after exposure for various periods up to

TABLE 13.
MOISTURE IMPEDANCE OF ALUMINUM PAINT FILMS.

Paint Coating ^a	No. of Coats	Film Thickness Mm.	Moisture Impedance ^b after:				
			Initial	3 mo.	6 mo.	12 mo.	18 mo.
Al paint-glycerol phthalate varnish No. 1	1	0.035	16	20	25	62	46
	2	0.056	30	35	41	52	224
Al paint-glycerol phthalate varnish No. 1d	1	0.020	11	19	134	171	45
Al paint-glycerol phthalate varnish No. 2	1	0.035	17	34	46	13	1.1
Al paint-glycerol phthalate varnish No. 3	1	0.033	6.8	9.2	10	17	9.6
Al paint-glycerol phthalate varnish No. 4	1	0.033	4.9	7.0	10	20	20
Al paint-phenolic resin varnish No. 1	1	0.026	22	62	95	47	1.2
	2	0.047	44	29	31	23	44
Al paint-phenolic resin varnish No. 2	1	0.029	9.3	20	23	1.8	°
	2	0.054	23	31	36	23	155
Al paint-phenolic resin varnish No. 3	1	0.030	15	15	38	45	33
Al paint-phenolic resin varnish No. 4	1	0.035	13	25	41	55	0.7
Al paint-phenolic resin varnish No. 5	1	0.032	16	16	34	30	30
Al paint-modified phenolic resin varnish	1	0.029	16	18	58	39	3.6
	2	0.053	31	29	54	56	43
Al paint-coumaron resin varnish	1	0.030	9.3	15	19	2.6	°
	2	0.050	27	24	28	24	35
Al paint-chlorinated diphenyl resin varnish	1	0.030	14	12	12	15	5.9
Al paint-petroleum resin varnish	1	0.037	13	12	38	33	19
Al paint-ester gum varnish..	1	0.024	4.7	7.1	7.7	0.3	°
	2	0.044	19	18	19	28	32
White lead-zinc oxide paint (oil base)	1	0.098	1.4	2.6	°	...	...
	2	0.174	2.8	4.6	0.3	°	...
White lead paint (oil base)..	1	0.054	1.3	0.1	°	...	...
	2	0.098	2.5	4.0	°	...	...

^a Aluminum paint made with 2 pounds of Standard Varnish powder per gallon of vehicle (240 grams per liter) except where paste is noted.

^b Based on film thickness of 0.025 mm. per coat.

^c Film was too brittle to remove intact for measurement.

^d Aluminum paint made with 2 pounds of aluminum paste per gallon of vehicle.

18 months. Data on two non-metallic pigment paints are included for comparison. How the mechanical properties of some of these paints changed at the same time is shown in Table 14. The excellent durability

TABLE 14.
MECHANICAL PROPERTIES OF ALUMINUM PAINT FILMS.

Paint Coating*	No. of Coats	Tensile Strength in Lb. per Sq. In. ^b after:—						
		Initial	2 weeks in lab.	1 mo. in lab.	3 mo. on roof	6 mo. on roof	12 mo. on roof	18 mo. on roof
Aluminum paint-glycerol phthalate varnish No. 1.....	1	200	303	385	1034	1750	2635	1815
	2	344	...	...	809	1222	2105	2220
Al paint-glycerol phthalate varnish No. 1 ^c	1	369	...	...	1400	2830	2680	2985
Al paint-phenolic resin varnish No. 1	1	1079	...	...	2010	1760	2790	480
	2	1084	...	...	1872	2883	3055	3425
Al paint-phenolic resin varnish No. 2	1	455	620	750	1470	1283	280	°
	2	798	...	...	1228	1673	1610	1735
Al paint-modified phenolic resin varnish	1	556	...	...	1134	1734	1535	785
	2	584	...	...	1000	1209	1428	1765
Al paint-coumaron resin varnish	1	423	...	...	960	613	700	°
	2	652	...	...	700	850	1010	1335
Al paint-ester gum varnish....	1	63	86	100	375	392	°	°
	2	189	...	...	570	648	859	915
White lead-ZnO paint (oil base)	1	252	...	...	623	°	...	...
	2	384	...	...	628	°	...	...
White lead paint (oil base)....	1	55	28	78	°	...	...	...
	2	72	...	...	350	°	...	...
Clear glycerol phthalate varnish No. 1	1	60 ^d	...	...	...	...	...	...
Per Cent Elongation in 2 inches								
Al paint-glycerol phthalate varnish No. 1	1	19.88	15.54	15.11	2.42	0.86	0.45	0.40
	2	36.07	...	...	5.78	2.60	1.27	1.33
Al paint-glycerol phthalate varnish No. 1 ^c	1	50.92	...	...	8.70	1.58	1.88	0.98
Al paint-phenolic resin varnish No. 1	1	7.32	...	...	1.66	0.74	0.45	0.04
	2	12.96	...	...	5.27	1.40	1.85	1.29
Al paint-phenolic resin varnish No. 2	1	11.94	10.60	7.66	1.97	0.76	0.00	°
	2	12.26	...	...	5.84	2.10	1.18	1.25
Al paint-modified phenolic resin varnish	1	12.58	...	...	4.06	0.96	0.99	0.23
	2	21.89	...	...	7.75	4.64	2.51	1.48
Al paint-coumaron resin varnish	1	15.50	...	...	0.96	0.53	0.00	°
	2	24.64	...	...	7.30	3.12	2.04	1.14
Al paint-ester gum varnish....	1	27.18	26.48	30.16	3.36	0.41	°	...
	2	31.46	...	...	9.02	2.22	1.40	1.06
White lead-ZnO paint (oil base)	1	17.06	...	...	0.54	°	...	...
	2	24.89	...	...	1.72	°	...	...
White lead paint (oil base)...	1	12.23	12.58	17.91	°	...	...	...
	2	14.56	...	...	0.68	°	...	...
Clear glycerol phthalate varnish No. 1	1	31.56 ^d	...	...	...	...	...	...

* Aluminum paint made with 2 pounds of Standard Varnish powder per gallon of vehicle (240 grams per liter), except where paste is noted.

^b All paint films were conditioned in air at 80° F. and 60 per cent humidity prior to the determination of strength and elongation.

^c Film was too brittle to remove intact for measurement.

^d Not exposed.

* Aluminum paint made with 2 pounds of aluminum paste per gallon of vehicle.

of aluminum paint films made with these synthetic resin vehicles is well brought out by these tests.

Resistance to Sulfur Compounds.

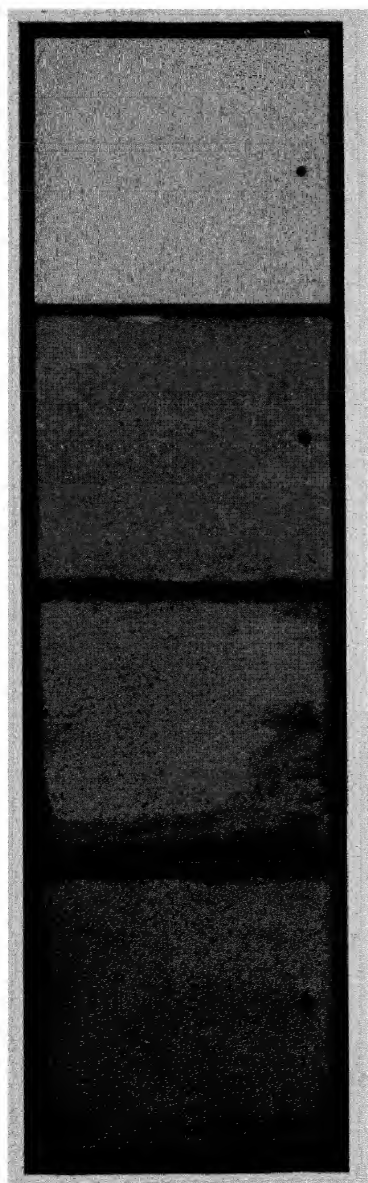
Aluminum as a base metal is unique in its resistance to sulfur and finds many applications for that reason. To cite only one example, aluminum molds and forms are used in the rubber industry; they resist the action of sulfur and no discoloration can result from the contact of the rubber-sulfur mixture with aluminum. Paints containing lead pigments are discolored by even small amounts of hydrogen sulfide. It is a marked advantage of aluminum paint, therefore, that it is inert to hydrogen sulfide and is not discolored thereby.

By way of test, a steel panel coated with aluminum paint (varnish vehicle) was suspended above a hydrogen sulfide generator in a hood where hydrogen sulfide was being used in analytical operations. The panel was in contact with air containing very appreciable quantities of hydrogen sulfide for a period of six months. No apparent discoloration or deterioration could be detected at the end of that period.

White paints containing lead pigment will discolor under the conditions prevalent in most chemical laboratories. Under these conditions aluminum paint has given an excellent performance in practical use. It may be used on walls, ceilings and equipment. It combines good lighting efficiency with high resistance to chemical fume. A varnish vehicle should be employed which does not contain more than very small amounts of lead drier.

A quantitative comparison of the effect of hydrogen sulfide upon white paints and aluminum paint is given in Table 15. A series of sheet iron panels were given one coat each of aluminum paint and several standard white paints. After thorough drying, they were suspended in a hood where hydrogen sulfide was being used in analytical operations. The reflectivity was measured after 3 days' exposure and after 12 weeks. The reflectivity of the panels with 3 days' exposure was measured without dusting off the surface in any way. The panels after 11 and 12 weeks' exposure were wiped lightly with a damp cloth to remove dust before they were measured. The initial reflectivities had run from 60 to 70 per cent; after 12 weeks' exposure one of the panels was as low as 24 per cent. Although the aluminum coated panel showed some loss in reflectivity, there was absolutely no yellowing of the paint. Rather a certain whitening of the surface had taken place, probably as the result of condensation of chemical fume. The white paints had all turned various shades of yellow to dark brown. The appearance of four of these panels is shown in Fig. 50.

Since the white paints do not show good hiding in one coat, it seemed desirable to repeat the test, using both one and two-coat surfaces, as well as exposure to a much lower concentration of hydrogen sulfide. The second series (B of Table 15) was hung in the laboratory near the hood



Panel No. 1.
Aluminum paint.

Panel No. 2.
Gloss mill white.

Panel No. 3.
Titanox-zinc oxide paint.

Panel No. 4.
Lithopone-zinc oxide-inert,
40-40-20 formula.

FIGURE 50. Effect of hydrogen sulfide upon white paint and aluminum paint; one coat of paint exposed to strong concentration of hydrogen sulfide for 12 weeks.

but not in it. Substantially the same comparative results were noted, but in lesser degree. The aluminum paint showed no yellowing, the gloss mill white was only slightly tinted, but the remaining white paints were considerably discolored.

TABLE 15.

EFFECT OF HYDROGEN SULFIDE UPON REFLECTIVITY OF WHITE PAINTS AND ALUMINUM PAINT.

A—Black iron panels suspended vertically over hydrogen sulfide generator in laboratory hood.

Panel No.	No. of Coats	Description of Paint	Per cent Reflectivity		
			Initial	After 3 days' Exposure	After 12 weeks' Exposure
1	1	Aluminum Paint with varnish vehicle	69	55	60
2	1	Gloss Mill White.....	68	45	39
3	1	Flat Mill White.....	59	39	30
4	1	White Lead-Zinc Oxide-inert, 55-35-10 formula	60	36	24
5	1	Titanox-Zinc Oxide	70	46	32
6	1	Lithopone - Zinc Oxide - inert, 40-40-20 formula	70	45	34

B—Black iron panels suspended in chemical laboratory, near but outside ventilated hood containing hydrogen sulfide generator.

Panel No.	No. of Coats	Description of Paint	Per cent Reflectivity	
			Initial	After 11 weeks' Exposure
7	1	Aluminum Paint with Spar Varnish.....	69	58
	2	" " " " " "	70	58
8	1	Gloss Mill White	68	63
	2	" " " " " "	70	61
9	1	Flat Mill White	59	50
	2	" " " " " "	68	49
10	1	White Lead-Zinc Oxide-inert, 55-35-10 formula	60	46
	2	White Lead-Zinc Oxide-inert, 55-35-10 formula	66	50
11	1	Titanox-Zinc-Oxide	70	56
	2	" " " " " "	75	52
12	1	Lithopone-Zinc Oxide-inert, 40-40-20 formula	70	52
	2	Lithopone-Zinc Oxide-inert, 40-40-20 formula	74	52

The reflectivities for the mill white paints are substantially lower than the values commonly given in published tables. These, however, are the values commonly obtained in practice when these paints are applied in one or two coats over very dark surfaces. When applied over white plaster or a very light surface, naturally the reflectivity of the

painted surface would be higher. Values as high as 85 per cent may be obtained when a sufficiently thick film of white has been built up.

A note on the use of aluminum paint to resist attack by hydrogen sulfide was published in the section of Chemical and Metallurgical Engineering entitled, "The Plant Notebook"²⁴.

"One of the large university laboratories has been having a great deal of difficulty with sulfide scale on copper dashing and cornices of the laboratory building. This situation was aggravated seriously because the hydrogen sulfide generator house was on the roof of the building. Bituminous paint is apparently ineffective but an aluminum paint has proven entirely satisfactory for elimination of the corrosion of the copper roofing parts.

This development indicates that many plant corrosion problems where sulfides are a serious factor may be helped materially by aluminum paint."

In many of the oil fields now being developed, corrosion of steel by hydrogen sulfide and other sulfur-containing substances is a serious problem. Furthermore, in these locations, it is difficult to protect metal with paint, since most paints are seriously affected by hydrogen sulfide. Not only does aluminum paint hold its color in the presence of hydrogen sulfide, but if made with the proper kind of varnish, the paint itself will prove durable and render good protection to most surfaces coated with it. However, an oil-base aluminum paint may not withstand some special conditions such as the combined attack of oil and hydrogen sulfide as met with in tank interiors, for example.

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Chapter 7.

Aluminum Paint in the Protection of Wood

Aluminum paint with its metallic pigment seemed quite appropriate for use in protecting metal. The use of aluminum paint in the protection of wood was an innovation, however, which was not so readily accepted. Although the laboratory tests on wood, as well as practical experience in using it, have been surprisingly satisfactory, nevertheless it has taken a long period of educational effort to secure any general acceptance of this use of aluminum paint.

The first published records of exposure tests of aluminum paint on wood showed a substantial advantage for aluminum paint over the conventional paints then employed for house painting. As early as 1920, Henry A. Gardner exposed several wood panels coated with aluminum paint at Washington, D. C. An examination after 52 weeks' exposure¹⁸ showed three coats of aluminum paint on white pine to be in "very good condition" and one coat of aluminum paint as primer under two coats of outside white to be in "good condition—very sound." The pine panel with three coats of outside white, however, showed extensive wood checking and cracking with paint flaking over these areas. The improvement effected by the use of aluminum primer was very marked.

Other tests by Aluminum Research Laboratories, Forest Products Laboratory, Scientific Section of the Paint Manufacturers' Association of the U. S., as well as important paint manufacturers, fully confirmed the finding that aluminum paint offered important advantages in the painting of wood. Instead of taking this development up historically, a better picture will be gained by first describing some of the structural characteristics of wood. A metal surface is ordinarily smooth, uniform, and non-porous. Roughening may be resorted to in order to increase mechanical adhesion, and special chemical or electrochemical procedures may be adopted to make the metal surface passive or non-reactive. No such necessity exists in the case of wood, but other problems even more difficult of solution present themselves.

Structure of Wood.

Wood is cellular in structure. From the standpoint of the painter, certain elements of this cellular structure are very important. First of all, wood has an oriented structure, commonly described as *grain*. The fibers giving the appearance of grain, for the most part, run lengthwise of the tree or log. When a log is cut at right angles to its axis, the end

surface is said to have *end grain*. The end grain view of a log presents a surface of concentric rings. These are annual growth rings; there is one for each year of the life of the tree. Their width varies from species to species and with the rate of growth of the individual tree. In softwoods, the annual growth rings consist of a soft, light colored part called the *spring wood* and a hard, darker colored part called the summer wood. In the lumber sawed from a log, the growth rings present certain characteristic aspects, depending upon the way in which the log is cut. If a board is cut so that its broad surfaces run radially, or approximately so, to the annual rings, they are termed *edge-grain surfaces*. If the broad surfaces of the board are tangent to the annual rings, they are *flat-grain* surfaces. Boards may be cut, of course, so that they are intermediate between the edge-grain and the flat-grain condition. The side of a flat-grain board that was nearer the bark of the log is the *bark side* and the other is the *pith side*.

In describing the microscopic structure of wood, I can do no better than quote from F. L. Browne¹ of the Forest Products Laboratory.

"The cellular elements of softwood structure consist very largely of tracheids which are long, narrow tubes running vertically in the tree. They are roughly from 2 to 4 mm. long by less than 0.03 mm. wide. There are also shorter elements, termed the ray cells, which run along radii of the tree trunk and at right angles to the tracheids. Tracheids and ray cells are not merely bundled together; they are firmly imbedded in a continuous matrix, the middle lamella, so that there are no spaces between elements through which liquids may move. The air enclosed in wood is mostly enclosed within the tracheids and wood cells. These cavities are not completely isolated from each other as in a honeycomb, however, because their walls are penetrated by small pits, covered by membranes, in which there are ultra-microscopic openings about 0.00002 mm. in diameter, large enough to permit liquids to pass slowly, but far too small to admit paint pigments.

"In the pines, spruces, larches, and Douglas fir, there are scattered through the structure certain long channels, called resin ducts, running both vertically and radially. These afford long, relatively large passageways provided they are not obstructed with resin. The true firs, hemlocks, cedars, cypress and redwood do not normally have such resin ducts.

SPRINGWOOD AND SUMMERWOOD

"The reason why the annual growth rings are readily distinguishable in wood is clearly revealed in the microstructure because the tracheids of the springwood and summerwood differ strikingly from each other. In springwood the tracheids are roughly square in cross-section with thin walls and large voids. The enclosed air

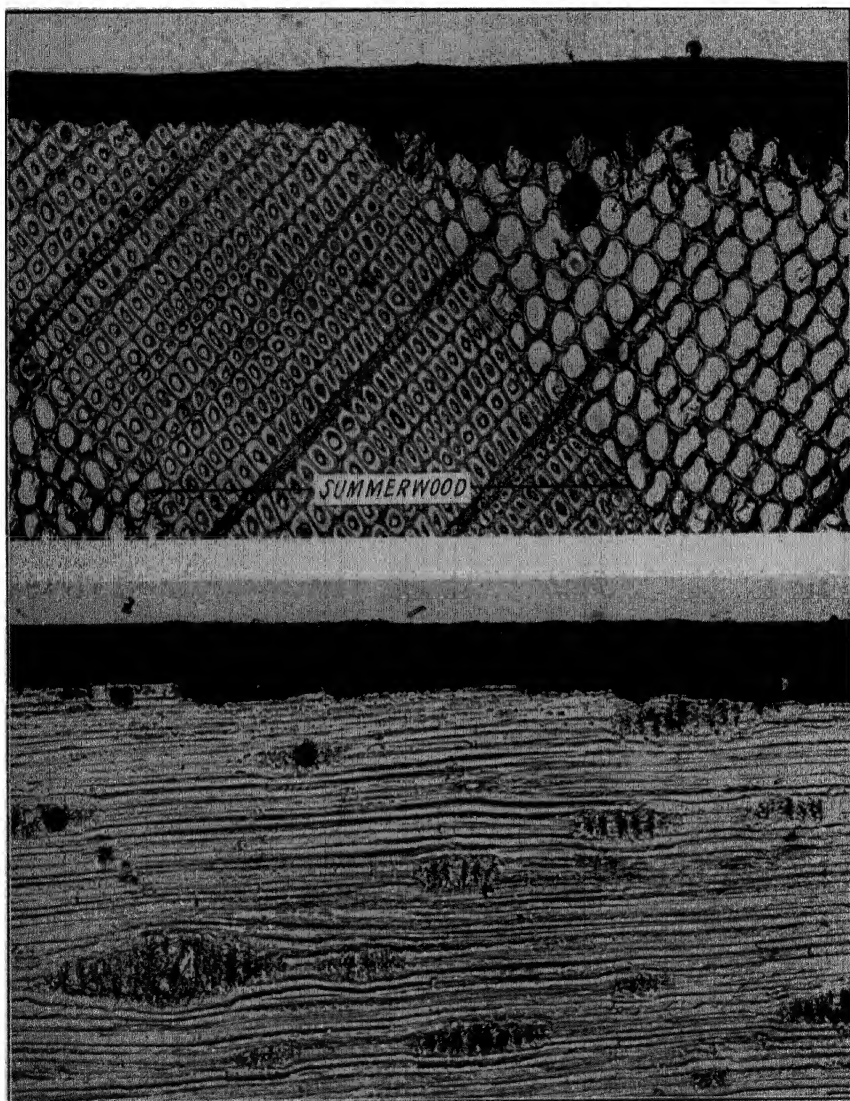


FIGURE 51. Photomicrographs of thin cross-sections of southern yellow pine with painted surface; taken by transmitted light.

The upper view is a transverse (end-grain) section and the lower view a longitudinal section. The white lead paint appears black because it is opaque. The paint penetrates into the cavities of only those tracheids that open into the painted surface because the pigment particles are far too large to pass from one cavity to another. Linseed oil from the paint, however, penetrates far deeper into the wood, as can be seen under the microscope. (Courtesy of Forest Products Laboratory.)

space in springwoods occupies roughly 80 per cent of the total volume while in summerwood it amounts to somewhere near 40 per cent. (*These differences are strikingly illustrated in Fig. 51*). Although summerwood has only half the capacity for holding liquids that springwood has, nevertheless liquids move through it much more readily than they do through springwood.

"Pieces of wood differ widely in the width of their annual rings, usually expressed as number of rings per radial inch, and in the proportion of springwood and summerwood in each annual ring. If the tree grew rapidly, the annual rings are wide. A high ratio of summerwood to springwood makes wood heavy and strong. Ring width and proportion of summerwood are the most important determining factors in paintability."

Moisture in Wood.

The cell walls in this complex structure consist principally of cellulose and lignin. They will absorb water, either by contact with moist air or liquid water. The wood substance not only absorbs but gives off water, depending on the environment in which it is placed. An equilibrium relationship exists, and when this equilibrium is reached in air of a certain humidity and temperature, a perfectly definite and reproducible moisture content is established in the wood. When the humidity of the surrounding air is increased, the wood takes up moisture and swells; when the humidity is decreased, the wood loses moisture and shrinks. The effect upon the dimensions and behavior of the wood will be profoundly influenced by the speed and manner in which the moisture is gained or lost. Moisture diffuses through the wood only slowly and when rapid moisture changes occur in the outer layers, large differential stresses may be set up in the wood and result in defects, such as warping, cupping and checking.

With increase in moisture content, the expansion of the wood in a longitudinal direction is quite small. In the radial direction of the trunk it may be substantial, and in the tangential direction it is even greater. According to the Forest Products Laboratory,¹⁷ the shrinkage of yellow pine or Douglas fir, when dried from a moisture content of 30 per cent to 0 per cent, is about 6.4 per cent in the flat-grain or tangential direction and 4.7 per cent in the edge-grain or radial direction. The complete shrinkage curves are given in the handbook. Haslam and Werthan²¹ have made an interesting series of measurements on the differences in dimensions of sections of yellow pine in the "wet" and "dry" condition. The over-all expansion in a radial direction was 4.6 per cent and in the tangential direction, 8.8 per cent. When, however, the measurements were made upon individual bands of summerwood and springwood, the summerwood was found to expand 9.4 per cent in the radial direction and 12.2 per cent in the tangential direction. The adjacent springwood,

however, was compressed, for it decreased 4.1 per cent in the radial direction and 2.0 per cent in the tangential direction. They point out the difficulties of making paint adhere to a surface undergoing such dimensional changes and the fact that the stress-strain conditions are most critical at the junction of spring and summerwood, where paint flaking is frequently observed to start.

When a board is cut with saw or plane, cells are cut open and a smooth but microscopically porous surface presented for painting. When paint is spread on such a surface, paint, both pigment and vehicle, can run into the cut cells but not beyond. The tiny openings between cells, called pits, are too small to permit passage of pigment particles, although liquids may pass slowly. Where end-grain is painted, there may be deeper penetration through the long tracheids, and it is a common observation that there is greater paint absorption in painting end-grain surfaces. There is also a characteristic difference in paint absorption over springwood and summerwood. There is usually less gloss over the springwood areas, indicating a greater volume absorption of vehicle than over the denser summerwood with thicker cell walls and smaller cell cavities.

Some Advantages of Aluminum Primer.

If one wishes fact or theory to explain the superior performance of aluminum paint on wood, there are a number of significant observations which can be made. First, may be mentioned resistance to moisture penetration. Rapid changes in moisture content, such as may be permitted by a paint film of high permeability, lead to checking and other evidence of wood weathering. The data presented in the previous chapter are ample evidence of the value of aluminum paint in preventing moisture penetration. The importance of paint in preventing rapid moisture *changes* has been well stated by Browne.²

"Weathering is a process of mechanical disintegration. It is primarily due to the shrinking and swelling of wood with changes in moisture content. The surface layers of a shingle, board or other piece of wood alternately absorb or lose moisture rapidly if exposed to rain and sunshine or to the everchanging humidity of the atmosphere. Changes in moisture content inside the piece, however, lag behind those in the surface layers because of the relatively slow rate of transfusion of moisture in wood. The lag tends to keep the interior at a relatively uniform moisture content and a constant volume, so that when the outside wood fibers swell and shrink they are alternately squeezed together and pulled apart. The action results in a slow breaking down and wearing away of the surface fibers, and sometimes more noticeably in 'raising of the grain', checking, cracking, and splitting of the wood, and the development of a soft, flabby surface in place of the hard, abrasion-resistant surface of new wood. Weathering may be augmented by

the action of frost, by the mechanical abrasion of rain, hail and wind, and perhaps by chemical changes in the wood substance brought about by the action of light, moisture, and oxygen. . . . The value of paint coatings for protecting wood lies in their effectiveness in retarding the absorption of moisture and its subsequent drying out."

It used to be an axiom with the "practical" painter, and many technologists as well, that the priming coat on wood should be thinned to secure deep penetration. In fact, one objection raised to aluminum paint in the early days of its use was that the varnish vehicle employed was too thick to permit ready penetration of wood. As a matter of fact, there is no reason why, after the open cells are filled with the paint, any advantage should accrue by deeper penetration of the vehicle. Vehicle penetrating the deeper lying cells cannot affect the adhesion of the paint film. Neither can it have any particular effect upon moisture absorption, for that takes place largely through the cell walls which can absorb moisture, even though the cell cavities are filled with oil. Aluminum paint does not penetrate deeply and the priming coat retains the necessary proportion of vehicle to act as a binder for the pigment. As a result, the priming coat does not rob the second coat of oil, as has been common experience with the conventional white primers. These views have been put forth in some detail by W. B. Roberts.²⁵ Thinning of the priming coat to obtain deep penetration even in the case of white pigmented paint, is now going out of style.

Not only is good initial moisture resistance desirable in paint for wood, but it is essential that it be retained if protection is to be maintained. Aluminum paint, as will be shown later, shows good adherence to wood, even under certain adverse conditions, and its durability and protection against moisture go hand in hand. Further observations on the behavior of aluminum paint on wood will be presented in connection with the experimental work to be described.

Early Tests on Moisture-Excluding Coatings.

During the World War, technologists at the Forest Products Laboratory were engaged in an extensive search for the best possible means of moisture-proofing wood propellers for airplanes. They discovered a highly effective means of accomplishing this by applying a varnish to the propeller, covering the tacky varnish coat with aluminum leaf, and finishing with spar varnish over the aluminum leaf. According to their method of rating, such a coating system had a moisture-proofing efficiency of 98 per cent. The application of the aluminum leaf was, however, a tedious and expensive procedure. Included in their tests were a number of paints and enamels, and among these was a varnish pigmented with aluminum powder, which ranked among the better coatings from the standpoint of their resistance to moisture penetration.²²

In a series of experiments in the years after the War, the methods of determining moisture-proofing power were revised and improved. New information was gained which ranked aluminum pigment high in its ability to increase the moisture-proofing power of a paint. According to Hunt,²² "coatings of varnish, enamel, or paint containing aluminum powder were next in effectiveness to aluminum leaf coatings. Such coatings, when properly applied and maintained, reduce the rate of moisture change in wood so that when exposed to practically saturated air for two weeks, only about 5 to 10 per cent as much moisture entered the wood as entered similar wood uncoated."

Forest Products Laboratory Method.

The method developed by Dunlap¹⁸ of the Forest Products Laboratory for determining the moisture-proofing efficiency of a coating on wood is essentially as follows. A wood specimen, usually birch, about 4"×8" in area, is coated with the paint or finish to be tested and brought to constant weight under standard conditions of temperature and humidity. It is then exposed to an atmosphere of high humidity for a definite period and the moisture absorbed is determined by weighing. From these two values and the moisture absorbed by a similar uncoated specimen, the moisture-proofing "effectiveness" is calculated.

For most tests, the specimens are a selected grade of yellow birch 4"×8"× $\frac{3}{8}$ " in dimensions and with carefully rounded edges and corners. The specimens were first conditioned in a chamber at 60 per cent humidity at 80° F., after which they were painted. After drying, the specimens were weighed and then placed in an air-conditioned chamber maintained at 95 per cent humidity at 80° F. At the present time, an initial humidity of 65 per cent and a final humidity of 97 per cent are employed by the Forest Products Laboratory in making these tests. The specimens may be weighed at shorter intervals, although for much of the work the increase in weight during a period of one week or two weeks in the humidity chamber was determined. To find the moisture-proofing effectiveness, a bare specimen of the same wood and same dimensions was carried through the test as a blank. The effectiveness of the coating was calculated by a comparison of the weight of moisture absorbed by the bare and painted specimens as follows: $\frac{A-B}{A} \times 100 = \text{percentage effectiveness}$

rating, where A=weight of moisture absorbed by bare specimen, and B=weight of moisture absorbed by painted specimen.

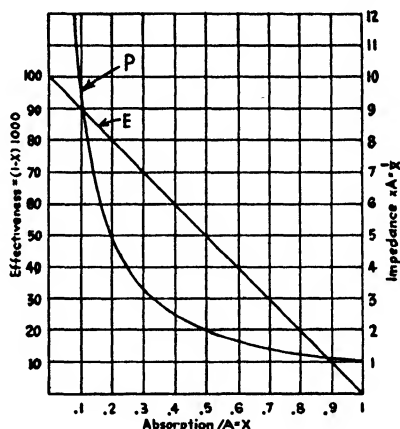
In such a test, the results give a picture of the combined effect of the permeability of the paint film and of the absorption characteristics of the wood. This is advantageous from one standpoint because the ultimate value of such a test is in determining the moisture change or rate of moisture change in the wood. Wood, however, is not homogeneous like metal; it is a cellular material, the structure and painting characteristics

of which will vary from board to board and from point to point in the same board. The wood, therefore, introduces a variable into the painting tests which is difficult to control. Differences in important structural characteristics of the panels themselves frequently lead to apparent inconsistencies in the results, and variations in thickness of the paint films introduce a further complication in the interpretation of the data obtained by this method. Nevertheless, some valuable information has been gained from the extensive series of tests carried out by the Forest Products Laboratory with this method.

Moisture Penetration Relations.

The permeability of a paint film, or the rate at which moisture penetrates it, bears a reciprocal relation to the moisture impedance, or resistance to moisture penetration. This is similar to the relation which exists between electrical conductivity and electrical resistance. The resistance to penetration by moisture increases linearly with thickness,

FIGURE 52. Relation between moisture absorption, moisture impedance and effectiveness rating of painted wood. Use effectiveness scale with Graph E and impedance scale with Graph P.



but the amount of moisture passing through the film in unit time does not decrease linearly with increase in thickness because of this reciprocal relationship.

The relation between moisture absorption, moisture impedance, and the effectiveness rating of painted wood is shown in Fig. 52.¹⁴ In this figure, A represents the moisture absorbed by bare wood under any given set of conditions, and X is the moisture similarly absorbed by the painted wood. Consider, for example, a single coat of paint which has an effectiveness of 19. The effectiveness rating of 19 (graph E) corresponds to an absorption ratio of 0.81, and this ordinate crosses the Curve P at a point corresponding to an impedance of about 1.24. If the single coat has an impedance of 1.24, two exactly similar coatings would have double this value, or 2.48, and three coats an impedance of 3.72. Following the abscissa of an impedance of 2.48, it is found to intercept

curve *P* at an absorption ratio of 0.4, which ordinate intercepts the effectiveness curve at 60 per cent. Similarly, the 3-coat impedance of 3.72 is found to correspond with an effectiveness value of 73. In an actual test by the Forest Products Laboratory method, effectiveness ratings of 19, 63, and 73 per cent were obtained in the application of one, two, and three coats of paint, respectively. The agreement with the calculated values of 60 and 73 per cent is quite satisfactory. It is apparent, therefore, that with single coats of paint of low impedance value, there is a large jump in the effectiveness rating after the second coat has been applied, even though the two coats offer exactly double the moisture resistance of a single coat. These arithmetical relationships between moisture permeability and moisture impedance must be kept carefully in mind in interpreting data obtained by the Forest Products Laboratory method and in comparing them with the impedance values.

Another point to be remembered is that the effectiveness rating may be profoundly influenced by the length of time the painted panel is held in the high humidity chamber. The effectiveness rating of a single coat of low impedance, for example, decreases as the period of test is extended, because the bare wood becomes saturated quickly and the painted wood at a slower rate. In a test, the apparent effectiveness rating of a single coat was 66, 57, 50, 46, 39, 36, and 25 per cent after test periods of 1, 2, 3, 4, 6, 7 and 14 days, respectively. In the earlier tests at the Forest Products Laboratory, the panels were conditioned at high humidity for two weeks; this was the practice followed by Wray and Van Vorst with some of the tests in their first paper on permeability.²⁷ Browne, in his later investigation, "Effectiveness of Paints in Retarding Moisture Absorption by Wood," employed a one-week period.⁸ Browne also employed 65 per cent humidity for the initial conditioning of the panels and 97 per cent humidity for the final conditions.

Forest Products Laboratory Tests.

Browne investigated the moisture-proofing power of aluminum paints, white and colored linseed oil paints, mixtures of aluminum powder with granular pigments, effect of vehicle composition and pigment concentration and effect of spray application.⁸ The moisture-proofing powers of these paints were determined on four woods,—southern yellow pine, northern white pine, Douglas fir and redwood. Determinations were also made on the paints as initially applied and after weather exposure for periods up to 36 months. The data indicate that one coat of paint seldom offers much protection against moisture movement over periods of a week or more. It does, however, slow down the rate of moisture change and may give quite adequate protection against short exposures to liquid water, as was shown by an 18½-hour test in a water spray.⁴ While the data on aluminum primers alone showed considerable variation, the application of two coats of granular pigment paints over the aluminum primer was found to give greater moisture-excluding efficiency

TABLE 16.

EFFECTIVENESS AGAINST MOISTURE MOVEMENT OF SOME PAINTS BEFORE AND AFTER WEATHER EXPOSURE

According to F. L. Browne¹¹

Effectiveness rating (in per cent) determined after one week's exposure to atmosphere of 97 per cent humidity. Symbols: E represents effectiveness rating after the number of months' exposure indicated by the subscripts

Description of Primer	Primer only		Primer plus 2 coats of white lead paint							Primer and 2 additional coats of similar paint						
	E_0	E_6	E_0	E_6	E_{12}	E_{18}	E_{24}	E_{30}	E_{36}	E_0	E_6	E_{12}	E_{18}	E_{24}	E_{30}	E_{36}
Al paste in varnish A (a).....	70	68	85	88	84	84	82	74	76	92	94	88	89	89	87	86
Al paste in Bakelite varnish.....	77	75	90	91	88	87	80	70	76	94	95	85	91	91	90	90
Al powder in varnish A.....	45	50	88	89	86	86	80	73	77	94	95	91	92	92	89	88
Al powder in Bakelite varnish.....	42	42	91	91	88	89	84	73	76	95	96	91	91	92	90	90
Al powder in 75-gallon ester gum varnish.....	12	16	86	88	83	80	74	63	67	90	93	87	87	87	83	83
Al powder in 33-gallon ester gum varnish.....	24	26	91	92	87	84	77	62	70	98	97	93	93	91	88	90
Al powder in glycerol-phthalate varnish.....	16	19	86	86	86	86	78	67	69	93	95	89	89	91	87	86
White lead in linseed oil.....	21	27	68	78	71	68	59	38	46	73	79	75	75	65	47	49
Titanox B-ZnO-Asbestine paint (b).....	20	20	69	81	67	57	55	38		70	79	77	77	81	70	62
White lead-ZnO-Asbestine paint (c).....	24	21	72	82	69	60	56	38		74	82	80	78	70	54	51

(a) Two pounds of aluminum paste or 2 pounds of Standard Varnish aluminum powder per gallon of vehicle.

(b) Titanox B 60 per cent, zinc oxide 30 per cent, asbestine 10 per cent.

(c) White lead 60 per cent, zinc oxide 30 per cent, asbestine 10 per cent.

E as measured is always the average effectiveness of exposed face and unexposed back of specimens. Tests of a large number of representative specimens at the end of the 36-month period, made by painting the exposed faces with aluminum paint of effectiveness 90 and then subjecting to the absorption test, show that the unexposed backs retain approximately the initial effectiveness, E_0 . The effectiveness of the face alone at any time T can therefore be computed from the formula: $E_T^F = 2E_T - E_0$, where E_T^F is the effectiveness of the exposed face alone at time T .

than was observed with three coats of the granular pigment paint. Primers highly effective against moisture movement were obtained by using the fine-mesh grades of aluminum powder or aluminum paste in certain synthetic resin vehicles.

A few of Browne's data on the moisture-excluding effectiveness of various paints are presented in Table 16.^{11, 4} The spreading rates of

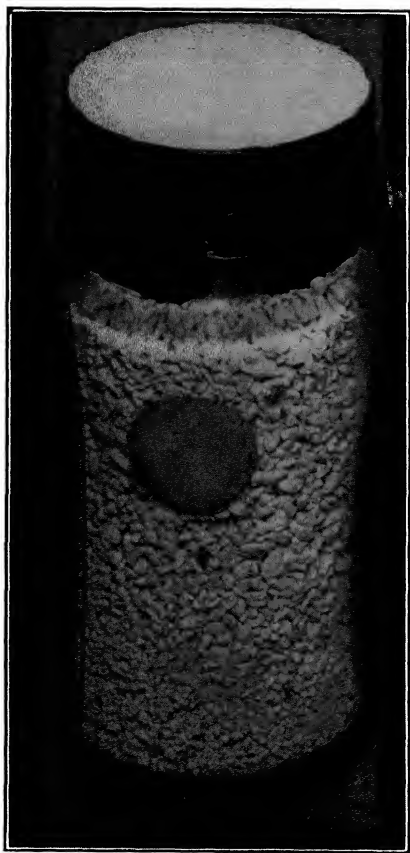


FIGURE 53. Assembly for testing the permeability of paint film applied to thin panel of wood. A narrow strip of aluminum foil, sealed to the wood with a special wax, closes exposed edge of wood and a wide strip of foil covers the line of seal to bottle top. The bottle contains activated alumina for the absorption of moisture passing through paint film and wood.

these paints varied considerably, so that comparison is not always between paint films of equal thickness—but nevertheless should represent conditions met with in practice.

Tests at Aluminum Research Laboratories.

The interpretation of the behavior of paint films on wood is helped by an understanding of the laws governing the penetration of detached paint films by moisture. This subject is discussed in some detail in Chapter 6. Wray and Van Vorst²⁷ have presented comparative data on the moisture

TABLE 17.

MOISTURE IMPEDANCE OF PAINTS ON QUARTER-INCH PINE PANELS
AFTER WEATHER EXPOSURE.

Paint Coating	No. of Coats	Moisture Impedance ^a after:					
		Initial	6 mo.	12 mo.	18 mo.	24 mo.	36 mo.
Al paint in varnish A.....	1	9.0	10	9.3	15 ^b	...	...
	2	47	71	89	82 ^b	...	...
	3	63	100	95	96 ^b	...	...
Al paint in varnish B.....	1	20	14	15	17	7.6	...
	2	77	52	66	57	74	26
	3	112	108	111	153	243	123
Al paint in varnish C.....	1	32	22	22	19	10	...
	2	61	59	72	64	79	57
	3	117	111	103	127	233	160
White lead-ZnO in varnish A	1	8.0	5.1	4.1	...	...	...
	2	16	16	11	11 ^b	...	...
	3	34	35	12	7 ^b	...	...
White lead-ZnO in linseed oil	1	4.9	2.6	2.0	...	...	...
	2	16	15	18	13	7.8	...
	3	23	21	26	27	28	6.1
High-strength lithopone in varnish A	1	12	4.2	3.7	...	...	...
	2	22	11	4.0	...	...	...
	3	31	18	14	11 ^b	...	...
High-strength lithopone in linseed oil	1	10	4.5	4.1	...	...	...
	2	16	13	7.7	8 ^b	...	...
	3	20	26	19	13 ^b	...	...
Gray glycerol phthalate enamel	1	6.1	8.2	6.0	10 ^b	...	...
	2	15	24	22	34 ^b	...	...
	3	27	36	40	48 ^b	...	...
Gray Bakelite enamel.....	1	10	6.5	5.9	8 ^b	...	...
	2	22	28	20	25 ^b	...	...
	3	29	39	31	36 ^b	...	...
Clear varnish B	1	8.2	6.2	5.4	3.7	...	...
	2	17	15	16	19	20	8.4
	3	18	16	16	18	21	12
Clear varnish C	1	14	11	9.6	11	6.5	...
	2	24	18	18	22	22	11
	3	36	27	26	35	36	21
Al primer (varnish A') ^c + 2 coats white lead-ZnO paint	3	35	33	38	40	29	5.3
Al primer (varnish B) + 2 coats white lead-ZnO paint	3	48	53	52	63	104	22
Bare wood panel ^d	0	3.3	2.8	3.4	4.5	4.8	3.2

Varnish A in this table is an 80-gallon ester gum varnish, varnish B an oil-modified glycerol-phthalate varnish, varnish C a 50-gallon phenolic resin varnish.

^a Each impedance is the average of tests on duplicate specimens.

^b Test discontinued after 18 months.

^c Varnish A' is a modification of varnish A with less chinawood oil.

^d Not exposed but run as a blank at each period.

impedance of different types of paint films alone and on wood, as well as a series of effectiveness measurements on some of the same paint films, as determined by the Forest Products method. These latter data are not, however, directly comparable with those of Browne because the test panels were weighed after a *two* weeks period in the high humidity chamber. A reasonable correspondence is observed between the data of Wray and Van Vorst on the detachel films and those on the $\frac{1}{4}$ -inch pine panels. It should be remembered, however, that the films on wood were applied by brushing and the films measured alone were made by spinning. Differences in the thickness of the films applied by the two methods could account for some of the discrepancies noted. A later series of measurements¹⁵ is given in Table 17. The paint films were applied to both faces of $\frac{1}{4}$ -inch pine panels and the moisture impedance of paint and wood measured after exposure to the weather for various periods up to 3 years. In making a test, a small disk of the coated wood was cut from the exposure panel and sealed to the top of a bottle containing a moisture absorbent (activated alumina), as shown in Fig. 53. These measurements bring out clearly the fact that the retention of adequate moisture resistance by paint films for long periods is more difficult to obtain than is adequate initial moisture-proofing power. Aluminum paints, particularly with synthetic resin vehicles, are satisfactory performers in this respect.

Early Tests of Aluminum Paint on Wood.

The early tests of H. A. Gardner for the Paint and Varnish Manufacturers' Association (see page 69) were so promising that a more comprehensive test of aluminum paint was started in January, 1924.¹⁸ This test was carried out in collaboration with Aluminum Company of America, and panels were exposed both at Washington, D. C. and New Kensington, Pa. For these tests the panels were prepared in duplicate by Gardner. Panels of five woods—white pine, Douglas fir, cypress, yellow pine and redwood—were included. The paints were aluminum paint made with both spar varnish and bodied linseed oil vehicles, zinc oxide-white lead, zinc oxide-titanox, white lead, and some modification of these formulas, notably the addition of 1.5 per cent of aluminum powder to the white pigmented paints. Aluminum paint was tested, both as a primer under the non-metallic pigment paints and also as a top-coat paint over the aluminum primer.

On the first examination of the Washington test panels after twelve months' exposure, the protective action of the aluminum paint, both as top coat and primer was readily apparent.¹⁸ The results on the first 30 test panels showed markedly better condition of paint film and wood where the aluminum primer was used than where the white paint was applied directly to the wood. This generalization held for all five kinds of wood and for the three different white paints employed. The improvement in condition as effected by the use of the aluminum primer



Panel No. 7. Yellow pine with 3 coats white lead paint. Panel No. 8. Yellow pine with 1 coat aluminum paint and 2 coats white lead. Panel No. 15. Cypress with 3 coats titanox-zinc oxide paint. Panel No. 16. Cypress with 1 coat aluminum paint and 2 coats titanox-zinc oxide paint.

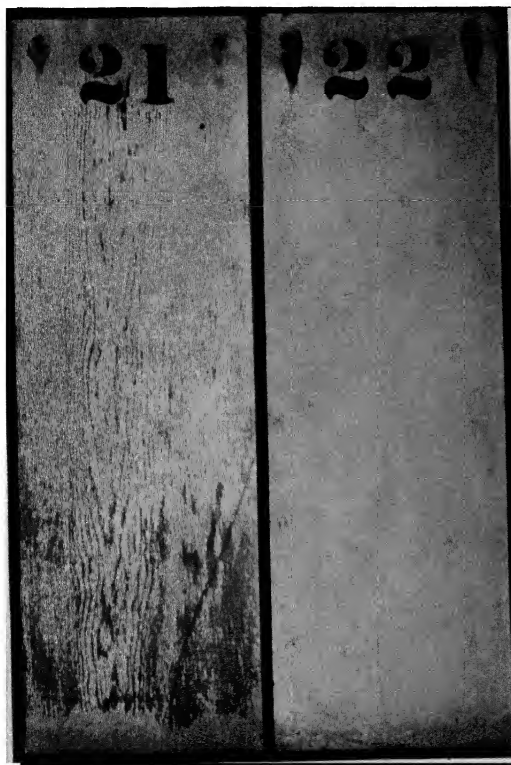
FIGURE 54. Appearance of wood test panels after 12 months' exposure at Washington. (Courtesy of H. A. Gardner.)

is graphically shown in the photographs reproduced as Figures 54 and 55. Five panels, one of each kind of wood, received three coats of aluminum paint and these were easily the best protected panels in the test. Some improvement in the durability of the white paint was effected by the addition of 1.5 per cent aluminum powder.

In the New Kensington test,¹⁶ as well as in the Washington exposure test, one point stood out above everything else. The five panels which received three coats of aluminum paint made with heavy bodied linseed oil showed no signs of wood weathering after 2 years' exposure, and the paint films themselves were in sound condition, without any sign of checking or chalking. Even after three years' exposure, their condition was excellent. The performance of the aluminum paint on the yellow pine was particularly noteworthy. No other paint combination gave adequate protection to the yellow pine. After three years' exposure,

the protection of the yellow pine was almost perfect, there being but one very fine wood check on the panel, with the wood still in good condition.

The next point is that the panels having an aluminum primer with two top coats of white were, in general, better protected than similar panels having three coats of white. There were fifteen pairs of panels with and without the aluminum primer, and in 12 out of 15 cases the aluminum



Panel No. 21.

White pine with 3 coats
white lead-zinc oxide
paint.

Panel No. 22.

White pine with 1 coat
aluminum paint and 2
coats white lead-zinc
oxide paint.

FIGURE 55. Appearance of wood test panels after 12 months' exposure at Washington. (Courtesy of H. A. Gardner.)

primer was distinctly helpful in protecting the wood. In two cases there was no choice, and in one, the panel with the aluminum primer was distinctly worse, although the difference in the grain of wood could easily explain this.

Primer Tests at Forest Products Laboratory.

The U. S. Forest Products Laboratory at Madison, Wisconsin, has an interest in paint because it is concerned with every means of making wood more serviceable. Its investigators recognized the potential importance of aluminum paint in protecting wood, and included it in the extensive tests it conducted to determine the merits of paints on various woods

and in different climates. These tests have been carried out over quite a period of years. Fortunately, they have been collected and summarized in a paper by Browne, by whom they were planned and supervised.⁵

One of these tests was begun in 1927 at Madison and had for its objective the determination of the painting characteristics of western larch. This lumber contains much summerwood and it is difficult to secure satisfactory paint life on it. Browne reports:

"In this series of tests, coatings over aluminum primer always proved distinctly more durable than the corresponding coatings over a white primer, whether the white primer was mixed with linseed oil in the customary manner or with a vehicle containing some of the varnish used in the aluminum paint. . . . The beneficial effect of initial aluminum priming continued after the inclined panels were repainted twice. At the time this is written by far the best panels of the series are those initially primed with aluminum paint. Presumably the continued good effect is due to the fact that aluminum priming not only prolongs the serviceable life of coatings but retards the flaking from summerwood if surfaces become paint-neglected."

Another series of tests was begun in 1928, and although it had for its primary object a study of the behavior of paints over wood impregnated with zinc chloride, it included tests of aluminum priming paint on southern yellow pine. With respect to these tests, Browne states:

"As in the tests on Western larch, aluminum priming-coat paint added materially to the durability of white lead paint and of lead and zinc paint, and the benefit of the aluminum primer continued after the panels had been repainted with white paints. When first painted, one final coat of the white paints failed to hide the color of the aluminum completely; as time passed, however, the coatings began to chalk and their opacity increased enough to hide the aluminum color satisfactorily. The repainted coatings showed no sign of the aluminum color at any time."

Another series of tests was begun in June, 1929, at Madison to investigate the painting characteristics of Douglas fir. Aluminum priming paints were included among those tested, and here again the aluminum primer proved more satisfactory than any other primer tested. Another series of tests on Ponderosa pine at Fresno, Cal., and Tucson, Ariz., in 1929, gave similar results. "In every case the use of aluminum priming paint material increased the life of the coating."

As Browne has stated,—“Many paint technologists have been reluctant to admit the merits of aluminum priming paint.” The suggestion has been made, for example, that the good results observed with aluminum priming paint were to be ascribed to the varnish type vehicle employed rather than to the aluminum pigment. The Forest Products Laboratory tests show that the use of the varnish vehicles with the white pigments

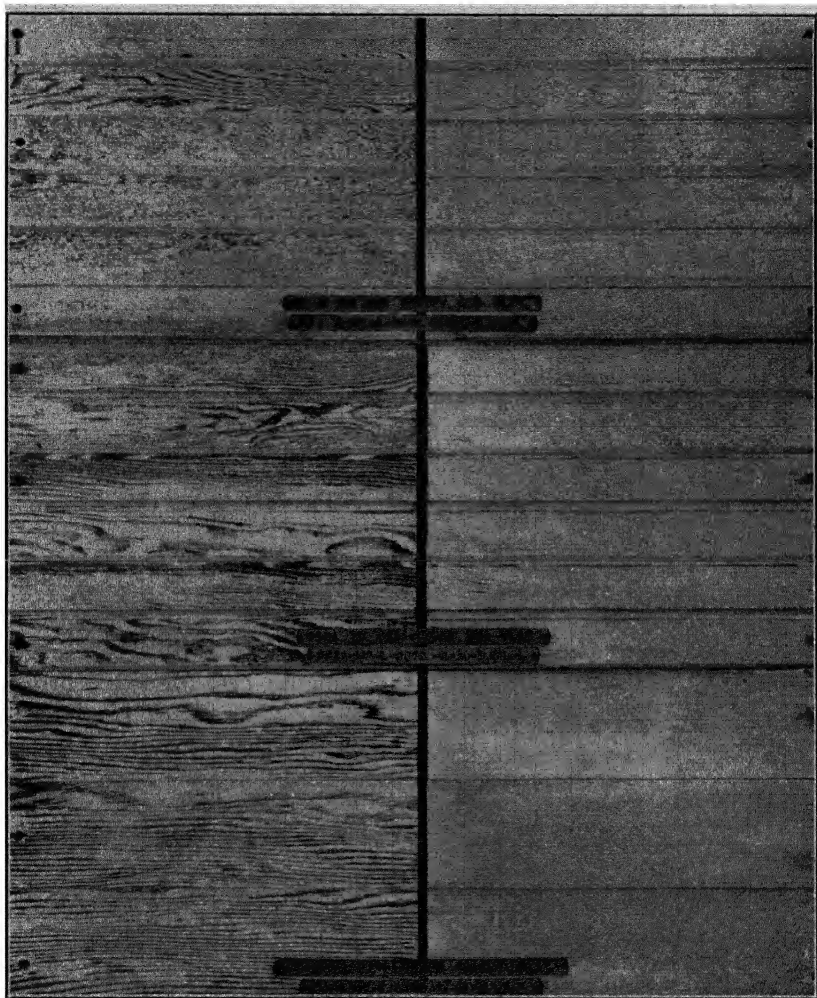


FIGURE 56. "Why aluminum priming paint is recommended for Douglas fir and southern yellow pine. These test panels of Douglas fir were painted and exposed to the weather for more than 6 years. The right-hand half of each panel was primed with aluminum paint, the left with white paint. On the top and bottom panels the white paint was pure white lead paint, on the middle panel it was a lead and zinc paint that conforms to Federal Specification TT-P-36. Two top coats of white paint applied over the primer on each panel." (Courtesy of Forest Products Laboratory.)

did not produce as satisfactory results as with the aluminum pigment, and the varnish used as primer alone was quite unsatisfactory. Similar results with varnish vehicle and white pigment were obtained on the St. Paul test fence (see next section), and in tests at Aluminum Research Laboratories.

In order to confirm its tests and acquire more data on other suggested priming paints, the Forest Products Laboratory began a series of tests of special priming paints in 1930 with exposures at Madison, Wis., Sayville, N. Y., Washington, D. C., Fargo, N. D. and Fresno, Cal. The tests were made upon beveled siding and each test panel consisted of one board each of redwood, northern white pine, Douglas fir and southern yellow pine. In order to minimize the effect of variations in the wood itself the panels, 72" long, were divided into three test areas; the middle area was primed in each case with a white paint, and the end areas with the special priming paints under test; two coats of white paint were then applied over the entire panel. The results of the exposure tests are summarized in Table 18 taken from the report on this work by Dr. Browne.⁶ Aluminum paint proved to be the best of the 20 special priming paints tested, whether it was used under white lead finish coats or under zinc-lead finish coats. A black paint made by mixing flaked graphite with varnish ranked next, and the third ranking paint was pigmented with a mixture of aluminum powder and white lead.

In all, nearly 200 test panels with aluminum priming paints under top coats of white were included in the several series of tests by the Forest Products Laboratory. In summarizing these tests, Browne states,⁶:

"Repeated comparisons of the durability of white paints on wood when applied over aluminum priming paint and when applied in the customary manner, using the white paint itself for a primer, consistently demonstrated a distinct superiority in service for paint applied over aluminum primer. The improvement in durability was manifested by a retardation in the rate at which paint coatings, embrittled with age, flaked from the bands of dense, horny summerwood present in softwood lumber. The benefit gained by priming with aluminum paint was greatest for woods that have much summerwood, such as southern yellow pine and Douglas fir. When repainting was neglected for some time, coatings applied over aluminum primer suffered less damage, and the surfaces were then more easily and durably repainted."

St. Paul Test Fence.

A test fence was erected at St. Paul by the Northwestern Paint and Varnish Production Club to investigate the effect of variations in priming coat formulation such as the proportion of pigment (white lead or white lead and zinc oxide, or titanox and zinc oxide), linseed

oil and turpentine. The woods painted were Norway pine, white pine, western red cedar and redwood. An aluminum primer made with a Bakelite varnish vehicle was also included in the test.²⁴

Browne has reported the results of an inspection of this test made in 1933 after 26 months' exposure.⁸ No advantage was found in adding extra turpentine to the white pigment primers, as has been generally recommended in the past. In fact, the primer mixed without turpentine was as good as any of the variations tried, but the test had not reached the stage where this conclusion might be taken as final. With respect to the tests with aluminum primer, the following statement is made:

"No coatings are now in better condition than the corresponding ones applied over aluminum priming paint. There is as yet no flaking from summerwood over aluminum primer except on two boards that are obviously unusually difficult to keep well painted. On both of these boards there is only a small amount of flaking on the area primed with aluminum, but a great deal of flaking on neighboring areas primed with white paint. There are a number of panels on which the coating is entirely sound over aluminum primer, but is flaking distinctly from summerwood of neighboring areas painted with white primers.

"It was pointed out previously that there was a tendency for the coatings to hold their gloss longer over the aluminum primer. As a result they also held dirt longer, and on the north side of the fence have not progressed quite as far in shedding this dirt. However, the discoloration by dirt tended to be somewhat more uniform and to be cast off again more uniformly over aluminum primer than over white primers.

"Checking of the white paints over aluminum primer follows exactly the same pattern and is no more conspicuous than it is over corresponding areas with white primers. On the south side of the fence the checking in the white lead paint can be seen with the microscope to extend down to the aluminum primer. Over white primers it probably extends down to the wood for reasons that have already been discussed.

"Three primers made with the varnish vehicle used for the aluminum primer, but containing respectively white lead, zinc oxide, and titanox B as pigments, are proving less satisfactory under white lead paint than the aluminum primer or than the ordinary white lead primers made with linseed oil. Checking of the white lead paint over the white primers made with the varnish is coarser and more conspicuous than it is over aluminum primer or over white linseed oil primer. There is also some flaking of the coating of white lead paint over the primers made with white pigments in varnish; the flaking is most marked over the varnish primer made with zinc oxide. The flaking, moreover, is coarser

and more conspicuous than the flaking of white lead paint when applied in the customary way."

Behavior of Paints on Different Woods.

That different woods show different painting and paint-holding characteristics is well known. These differences extend not only to different species but to different grades of lumber in the same species. Edge-grain and flat-grain surfaces also show important differences. In fact, different areas of the same board may show appreciable differences in painting characteristics. All of these facts have been demonstrated in the different exposure tests which have been discussed in the preceding sections of this chapter.

In the initial application of paint, to softwoods at least, there are few differences noted except in the amount of paint or paint vehicle absorbed. This is reflected in differences in spreading rates; they are usually of minor importance, however. A few woods may contain extractives which have an effect sometimes favorable, sometimes unfavorable, upon the durability, but which is usually unimportant in comparison with the effect of physical structure.⁹ The most important differences are in their paint-holding characteristics, particularly during the later stage of their serviceable life. When the paint film has aged to the point of brittleness, and moisture changes in the wood are becoming rapid, then the woods with wide bands of summerwood show an increasing tendency to let go of paint films. In fact, Browne has plotted the durability of the paint coating in months as a function of the specific gravity of the wood and found the relationship to be roughly linear, except for a few woods.⁷ The specific gravity is a rough measure of the amount of summerwood, for the summerwood usually has a specific gravity of two to three times that of springwood. The effect of wood structure on paint durability is again demonstrated by the New Kensington test fence.

New Kensington Test Fence.

Although hundreds of panel tests carried out at Aluminum Research Laboratories by Mr. Wray demonstrated the advantages of aluminum priming on lumber, the shortcomings of tests on small panels were not overlooked. A comprehensive test was therefore started in 1931, on a substantial scale and under conditions simulating actual building practices as closely as possible.²⁸ A test fence was erected which was 112 feet long and 6 feet high; it was divided into 28 sections each measuring 4 feet wide and 5 feet high. In building the fence, two-by-four studding, spaced on 2-foot centers, was covered both back and front with wood sheathing; building paper was applied on the south side over the sheathing, and the various kinds of siding nailed on top. The fence was closed at the top with a small sloping roof with eaves that projected slightly, and a water table was placed at the bottom.

The lumber for the tests, applied in the form of siding, included red cedar (edge and flat grain), redwood (edge and flat grain), western white pine (mixed grain), cypress, yellow poplar, Douglas fir, west coast hemlock, Englemann spruce, western yellow pine, and southern yellow pine (long and short leaf). These woods represent species employed for siding purposes in different sections of the country. Each panel comprised 10 to 14 four-foot lengths of siding, the number depending, of course, on the width of siding in the pattern employed with each kind of lumber.

The panels were grouped in pairs; one panel of each wood was primed with aluminum paint and a comparison panel was primed with white paint. The aluminum primer was applied by spray equipment designed for the mill priming of lumber. The wood was therefore coated on all sides with aluminum paint and air-dried before the siding was nailed to the test fence. The duplicate sections primed with white paint were coated after erection. An 80-gallon ester gum varnish was employed for the aluminum primer, using 1.5 pounds of Standard Varnish powder per gallon of vehicle. The white paint was a high-grade house paint (white lead 55%, zinc oxide 35%, inert 10%) reduced for the different coats according to the directions of the manufacturer. After priming, two coats of the same white paint used as primer were applied over all the sections, whether primed with aluminum or white.

Although beginning signs of failure were noted during the first year's exposure on a few of the sections primed with white paint, decided signs of failure were not observed until the second year. These cases were largely confined to the lumber with wide bands of summerwood and to the sections primed with white.

After three years' exposure, all sections primed with white paint except the edge-grain redwood and cypress, showed some flaking from the summerwood bands, and even the latter woods showed slight failure on the bottom boards. On the red cedar, the flaking was much less pronounced. The paint was beginning to show very slight failure on a few of the sections primed with aluminum paint, such as the west coast hemlock, western yellow pine, with long-leaf southern yellow pine. All other aluminum-primed sections were still in good condition.

Final inspection, after four years of exposure, showed that all sections of the fence which had been primed with white paint, except the edge-grain redwood and cypress, were in need of repainting. The white-primed edge-grain red cedar, which had previously shown but slight failure, showed moderately fine paint flaking to the wood, with very slight wood checking; similar results were obtained on the flat-grain red cedar, although the failure on the white-primed section was more pronounced. On the corresponding aluminum-primed sections there was no wood checking and the paint film was intact. These sections are illustrated in Figure 57. Two sections of edge-grain red cedar primed with aluminum paint made with the synthetic resin vehicles were in good condition.

On the edge-grain redwood there was very slight paint flaking on the white-primed section, particularly on the bottom board, whereas there was no such failure on the aluminum-primed section. Throughout the fence it was observed that the paint checking on all sections was of about the same degree, whether over the white primer or over the aluminum primer. A different type of failure was observed on the flat-grain redwood primed with white paint. The grain was raised badly on a number of boards. This caused very bad flaking of the paint down to the wood,

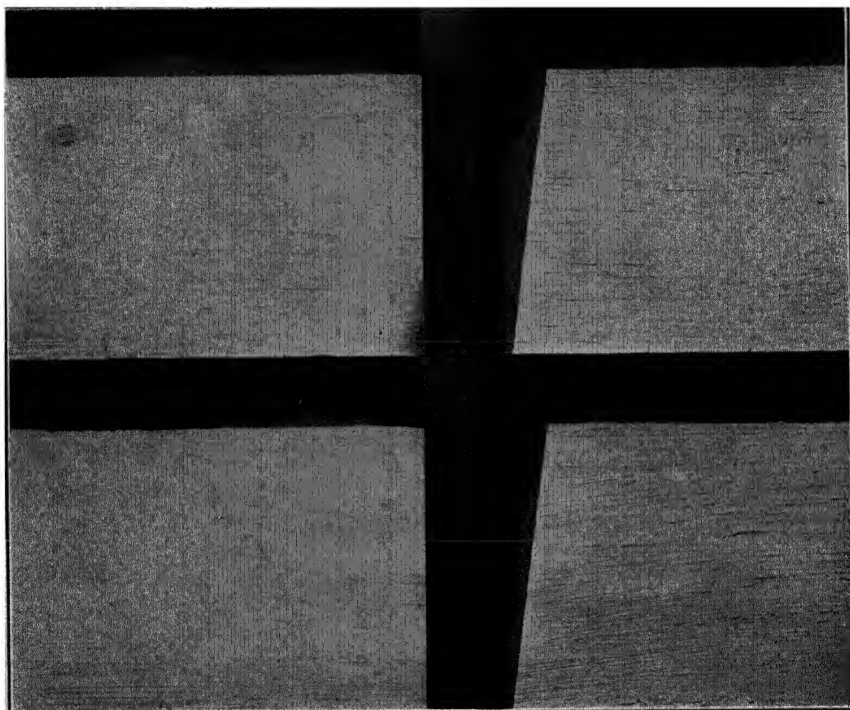


FIGURE 57. Edge-grain red cedar siding after 4 years' exposure at New Kensington. Aluminum-primed lumber on left half; white-primed lumber on right; two top coats of white paint on each.

on these areas. The aluminum-primed section, on the other hand, was still sound, showing no paint flaking, although there was some evidence of raised grain on one or two boards. These sections are shown in Figure 58.

A typical example of the usual type of paint flaking from the summerwood bands is shown on a section covered with white pine and primed with white paint; this is illustrated in Fig. 59. There was also considerable fine wood checking on this section. The paint of the duplicate aluminum-primed section is sound, although a number of the boards

showed some splitting and fine cracks. This lumber was warped very badly as received; in fact, it was so badly warped that it was difficult to paint it in the special equipment which was used. This may account for some of the splitting which was observed.

The cypress sections were both in excellent condition, confirming F. L. Browne's previous results concerning the painting characteristics of cypress. There was very slight evidence of paint flaking on the bottom board of the cypress section primed with white paint. These two

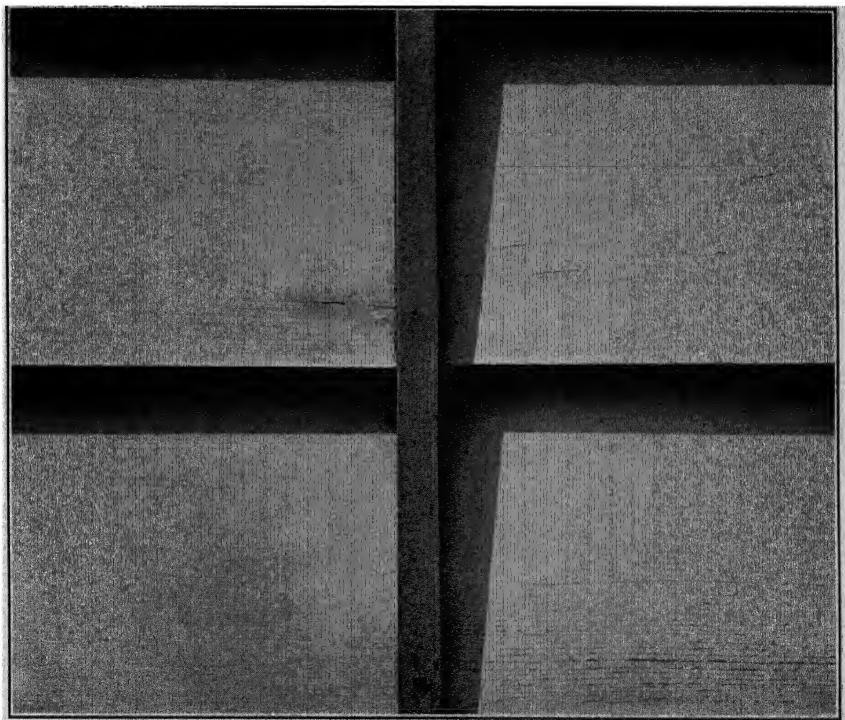


FIGURE 58. Flat-grained redwood siding after 4 years' exposure at New Kensington; aluminum-primed lumber on left half; white-primed lumber on right; two top coats of white paint on each.

sections were in decidedly the best condition of any of the sections in the fence. The next two sections, which were of yellow poplar, were in quite different condition, however, as will be seen in Fig. 60. Again the white-primed section showed considerable flaking of paint from the summerwood, with numerous fine wood checks. The paint on the aluminum-primed poplar was still sound.

Early failure was noted on spruce and hemlock which had been primed with white paint. After four years' exposure, however, the paint failure on the white-primed Douglas fir was almost as marked as on the spruce



FIGURE 59. White pine siding after 4 years' exposure at New Kensington. Aluminum-primed lumber on left half; white-primed lumber on right; two top coats of white paint on each.

and hemlock after four years. This section is shown on the right in Fig. 61. The corresponding section on the left, primed with aluminum paint, is in sound condition. The sections of western yellow pine (*Ponderosa* pine) are shown in Figure 62, and those of southern yellow pine, short-leaf, are shown in Figure 63. The failure of the white paint on these sections is quite typical of the similar failures which have been obtained with these woods painted in this manner in other tests. Very slight failure of the paint coating on the corresponding sections primed with aluminum paint was found, with a small amount of fine wood checking.

On each of the eleven species of wood which were tested, the presence of the aluminum primer enabled the paint coating to protect better and longer and present a better appearance than did the use of the white primer. While this difference was not so pronounced in the case of a few of the woods, it was sufficient to be worth while; with the other woods, it represented an increase in the life of the paint coating of from one to two years. And finally, the aluminum-primed siding presented in

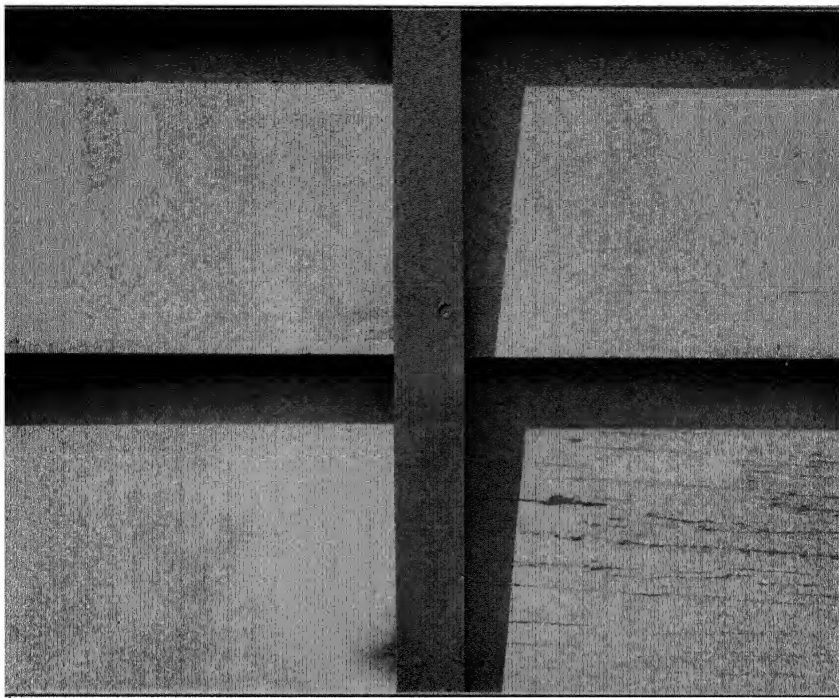


FIGURE 60. Poplar siding after 4 years' exposure at New Kensington. Aluminum-primed lumber on left half; white-primed lumber on right; two top coats of white paint on each.

every case, a better surface for repainting. This, of course, makes the value of the aluminum primer cumulative over a period of years.

Vehicles for Use on Wood.

The determination of the proper type of vehicle for use in aluminum paint on wood presents a number of problems. A knowledge of the structure of wood and its susceptibility to swelling and shrinkage with change in moisture content suggests that a more distensible vehicle is required than is necessary for aluminum paint for use on metal. Some of the earliest tests showed, for example, that vehicles of the conventional spar varnish type were not "elastic" enough to give the best service on wood outdoors. There were also other indications that difficulty would be experienced from checking of lead and oil top coats if the aluminum priming coat remained too soft and flexible. Many tests were therefore conducted to determine the best types of vehicle for use on wood.

House painters have been accustomed for years to the mixing of paste pigments with linseed oil. While the use of aluminum powder

in raw or boiled linseed oil is more feasible on wood than on metal, it still is subject to too many objections to be recommended. The use of a bodied linseed oil with added thinner is not a radical departure from conventional painting practices and has given satisfactory results,



FIGURE 61. Douglas fir siding after 4 years' exposure at New Kensington. Aluminum-primed lumber on left half; white-primed lumber on right; two top coats of white paint on each.

both in laboratory tests and in practice. It was soon discovered, however, that very long oil varnishes possessed certain advantages over the bodied linseed oil type of vehicle, and their use has become quite general.

Commercial considerations have influenced the trend in vehicle development. Many makers and users of aluminum paint wanted a vehicle which was suitable for use on both wood and metal, and long oil varnishes of certain characteristics seemed to meet these requirements. In recent years, synthetic resin varnishes which give excellent service with aluminum pigment on wood, both as primer and top coats, have become available.

The principal use of aluminum paint on wood has been as a primer

under white or tinted pigments. The use of white or light tints in house painting is so well established that the idea of aluminum paint for top coats has found only limited acceptance. Here and there a pioneering spirit has used aluminum paint for top coats, as well as the

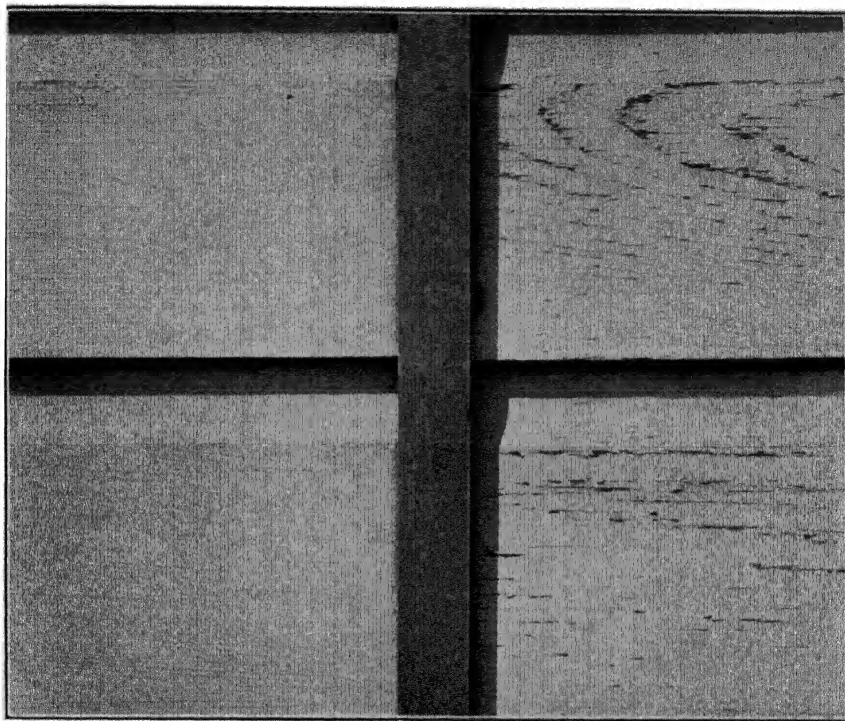


FIGURE 62. Ponderosa pine siding after 4 years' exposure at New Kensington. Aluminum-primed lumber on left half; white-primed lumber on right; two top coats of white paint on each.

priming coat, and been agreeably surprised to find that it looked much like other houses. Friends and neighbors did not recognize it as a metallic paint or anything out of the ordinary. The real surprise, however, has been in the extended life and protective value of the aluminum paint. The use of aluminum paint for all coats on wood is increasing, particularly in industrial plants, in company towns, on farm buildings, and on cottages and buildings at the seashore.

Interesting examples of the durability of aluminum paint on wood have been called to the author's attention by F. L. Browne. These are two test panels of Douglas fir, protected with two coats of aluminum paint made with an 80-gallon ester gum varnish vehicle, which are in excellent condition after 8 years' exposure at Madison, Wisconsin. Dr. Browne states: "The coatings are in perfect condition except for a few

end checks in the wood and a blemish on the lower board of panel No. 349, which is a pitch pocket in the wood. Matched specimens of boards of Douglas fir were painted at the same time in 1927 with 3 coats of white lead paint and 3 coats of lead and zinc paint. All of these panels showed bad disintegration of the coatings over the bands of summerwood in about $3\frac{1}{2}$ years' time." One of the aluminum painted panels is shown in Fig. 65.

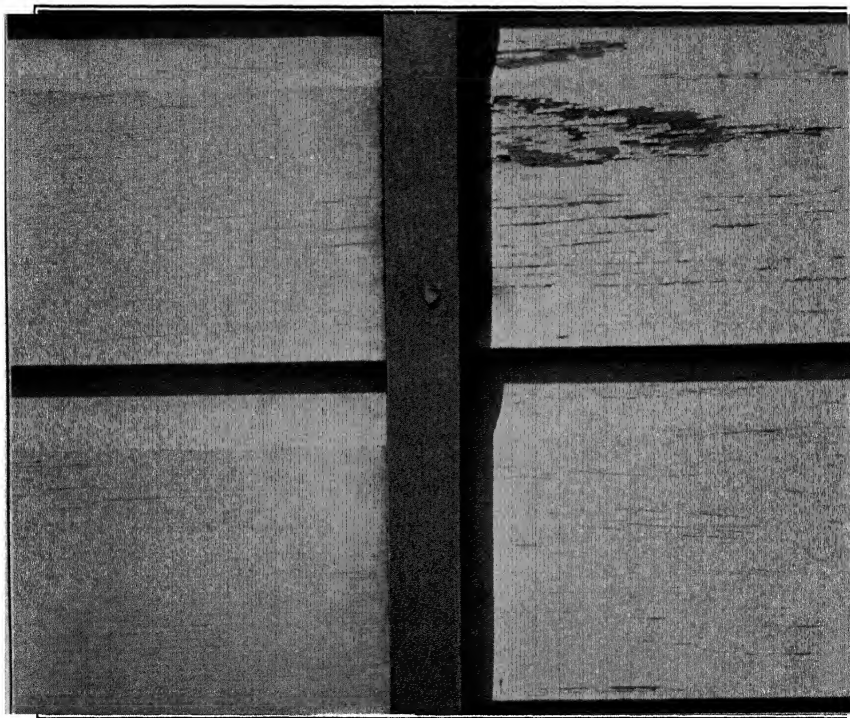


FIGURE 63. Southern yellow pine siding after 4 years' exposure at New Kensington. Aluminum-primed lumber on left half; white-primed lumber on right; two top coats of white paint on each.

One of the major investigations which R. I. Wray has been conducting at Aluminum Research Laboratories has been on aluminum paint for use on wood. The effect of vehicle on aluminum paint performance on wood is illustrated by a series of panels from these tests, as shown in Figure 66. These panels received two coats of paint on the lower portion of the panel and three coats on the upper third. Panel 43 was made with an aluminum paint, the vehicle of which was an 80-gallon ester gum varnish, and the paint, after 44 months' exposure, is in good condition on both the 2- and 3-coat areas. Panel 44 was coated with an aluminum paint made with an ester gum varnish about 50 gallons in

length, and the performance on the 2-coat area is not as satisfactory as in the case of the preceding panel. Apparently this vehicle is about on the border-line with respect to distensibility, for the aluminum paint made with a 40-gallon ester gum varnish (conventional spar varnish), as shown on panel 45, gave decidedly inferior service on the 2-coat area, although still in good condition where three coats were applied. Panel 52 is in excellent condition; the aluminum paint on this panel was made

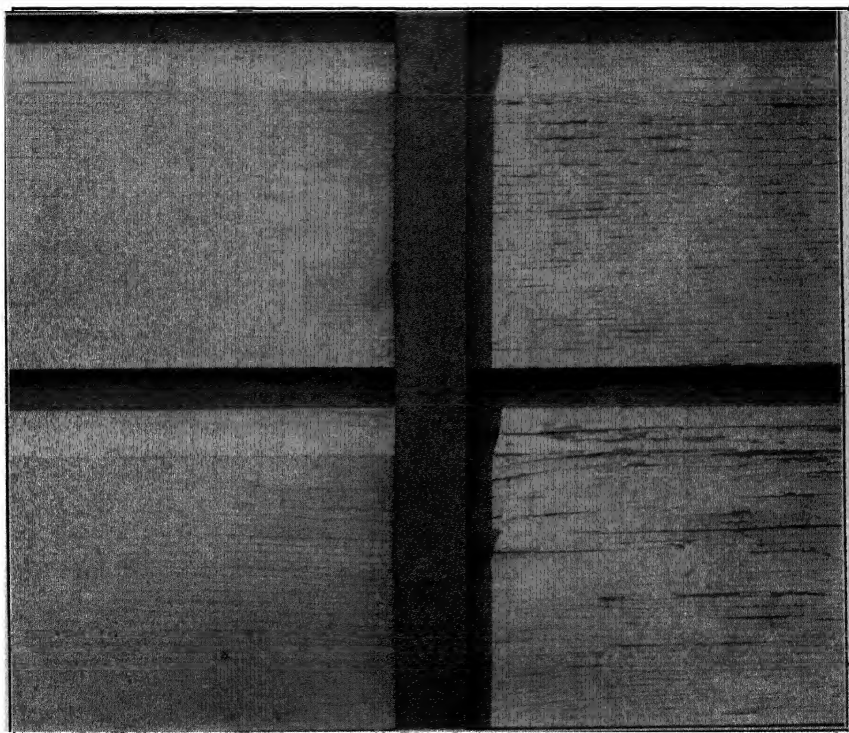


FIGURE 64. Englemann spruce siding after 4 years' exposure at New Kensington. Aluminum-primed lumber on left half; white-primed lumber on right; two top coats of white paint on each.

with a kettle-bodied linseed oil to which had been added 40 per cent of thinner. In a general way, it may be said that the aluminum paints on these four panels showed an increasing durability as the length in oil increased.

Another series of tests, in which the aluminum paint was used only as primer, showed somewhat similar results. Panels 132 to 136, Figure 67, were primed with aluminum paint; a different vehicle was employed for the aluminum primer on each panel. All the panels were then given two top coats of white paint pigmented with white lead, zinc oxide and

inert filler made in the 55-35-10 ratio. The aluminum primer on panel 132 was made with a 40-gallon ester gum varnish similar to that used on panel 45 in Figure 66. The length in oil was increased by adding 15 per cent raw linseed oil to the vehicle for the aluminum paint used on panel 133 and 50 per cent raw linseed oil in the case of the vehicle used for the aluminum paint on panel 134. The aluminum primers used on panels 135 and 136 were similarly increased in oil length by the addition of 15 per cent and 50 per cent, respectively, of boiled linseed oil. In comparison with panel 132, the aluminum primer made with the oil-blended varnishes gave better performance than did the aluminum

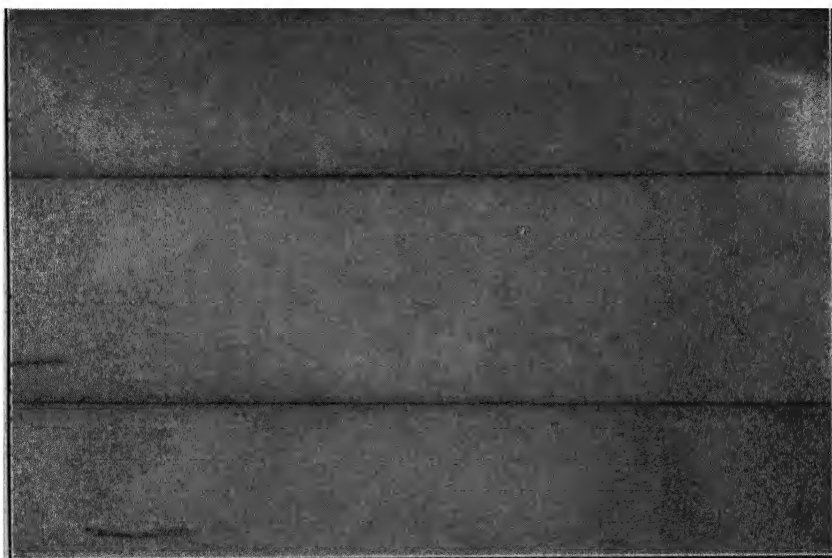


FIGURE 65. Douglas fir (sap side) protected with 2 coats of aluminum paint made with ester gum varnish vehicle, after 8 years' exposure at Madison, Wisconsin. (Courtesy of Forest Products Laboratory.)

primer made with the 40-gallon ester gum varnish. All five panels, however, were in better condition after 3 years' exposure than panel 153, which received three coats of white paint.

Still another series of tests, illustrating the effect of vehicle upon aluminum primer performance is shown in Figure 68. In this test, each panel was divided into two areas; the right half was primed with aluminum paint and the left half with a white lead-zinc oxide-inert paint of the 55-35-10 formula. Each panel then received two top coats of the same white paint. Panels 293, 294 and 299 were primed with aluminum paints made with 80-gallon ester gum varnishes. These varnishes were, however, from three different manufacturers and presumably differed somewhat in composition and characteristics; they

all gave satisfactory results. This series is interesting because the aluminum primer used on panel 300 was made with a 50-gallon Bake-lite varnish and that on 301 was made with an oil-modified glycerol phthalate varnish. These two synthetic resin vehicles gave satisfactory results over wood,—results which have been fully confirmed by later tests. The sharpness of demarcation of the line between white primer and aluminum is striking. Even wood checks and cracks starting under the white primer stop when they reach the area primed with aluminum

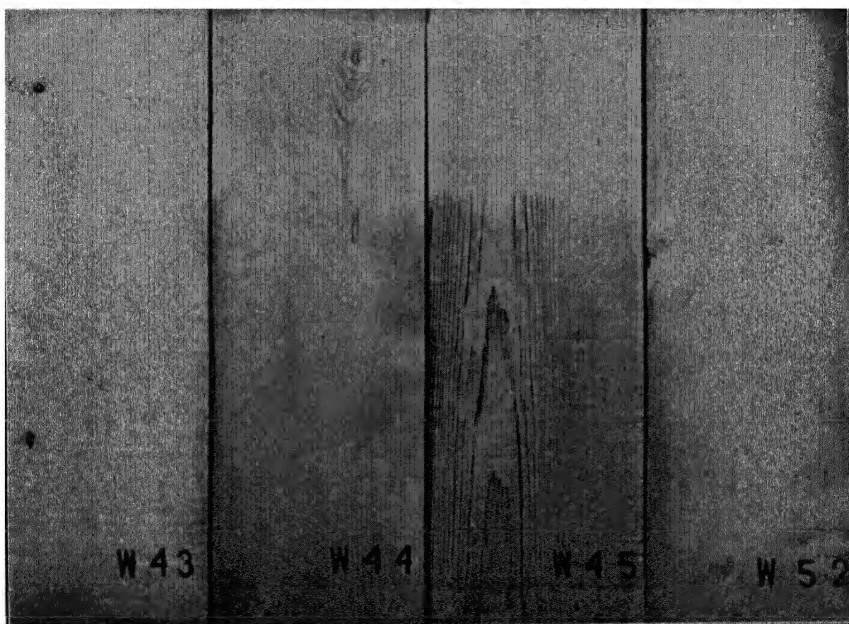


FIGURE 66. Western yellow pine with 2 coats of aluminum paint on lower portion and 3 coats above, after 44 months' exposure at New Kensington; aluminum paint made with 80-gallon ester gum varnish (No. 43), 50-gallon ester gum varnish (No. 44), 40-gallon ester gum varnish (No. 45), kettle-bodied linseed oil (No. 52).

paint. The panels shown in Figures 66, 67, 68 and 69 were exposed at an angle of 45° facing south, at New Kensington. This condition gives accelerated weathering in comparison with panels exposed vertically.

Specifications for very long oil varnishes and synthetic resin varnishes suitable for mixing aluminum paint for application to wood, are given in the appendix.

Back Painting of Lumber.

For a number of years, paint technologists have recognized the fact that many failures of paint on houses, especially premature failures, have been the result of other causes than poor paint or painting prac-

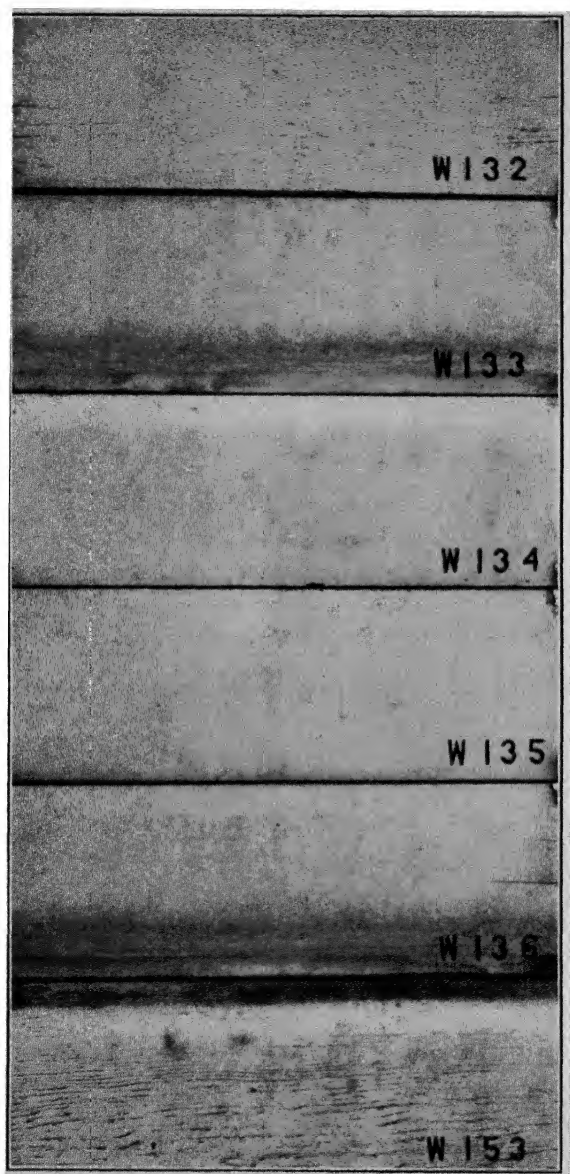


FIGURE 67. Aluminum primer on western yellow pine with 2 top coats of white paint, after 3 years' exposure at New Kensington; aluminum primer made with 40-gallon ester gum varnish (No. 132), same varnish with 15 per cent raw linseed oil (No. 133), same varnish plus 50 per cent raw linseed oil (No. 134), same varnish plus 15 per cent boiled linseed oil (No. 135), same varnish plus 50 per cent boiled linseed oil (No. 136); panel No. 153 received 3 coats of the white paint.

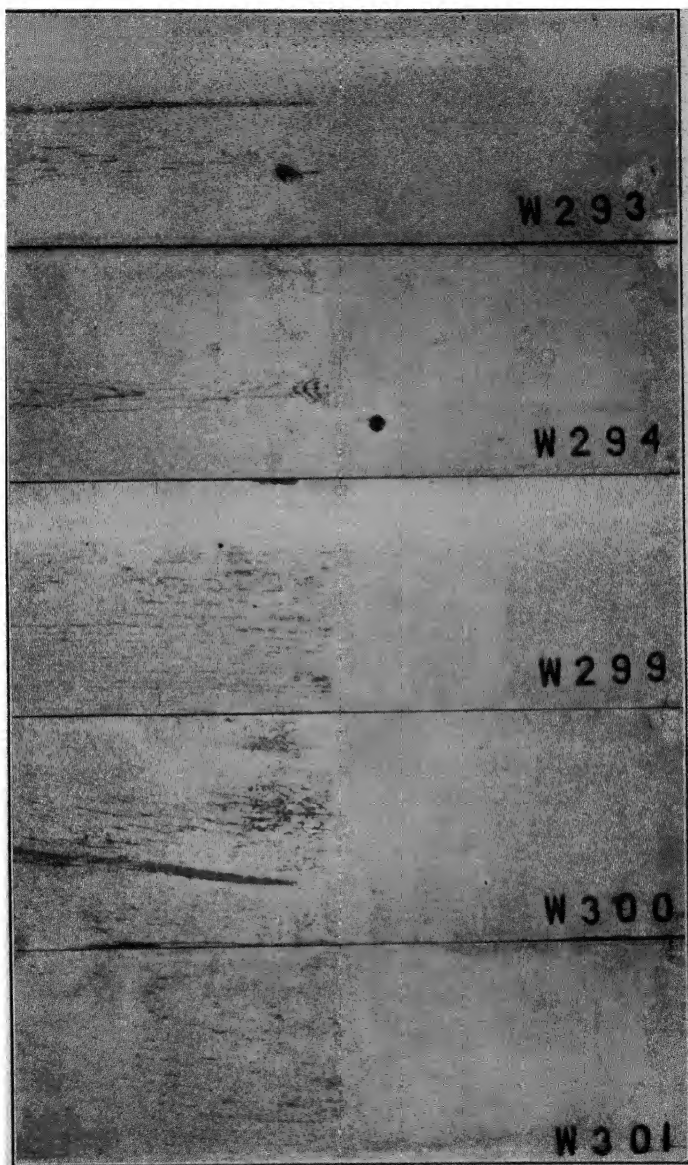


FIGURE 68. Effect upon paint durability of vehicle used in aluminum primer; right half of each panel primed with aluminum paint, and left half with white lead-zinc oxide paint; each panel received 2 top coats of the white paint; panels Nos. 293, 294 and 299 primed with aluminum paint made with 80-gallon varnishes from three different manufacturers; panel No. 300 primed with aluminum powder in 50-gallon Bakelite varnish and panel No. 301 primed with aluminum powder in glycerol-phthalate varnish.

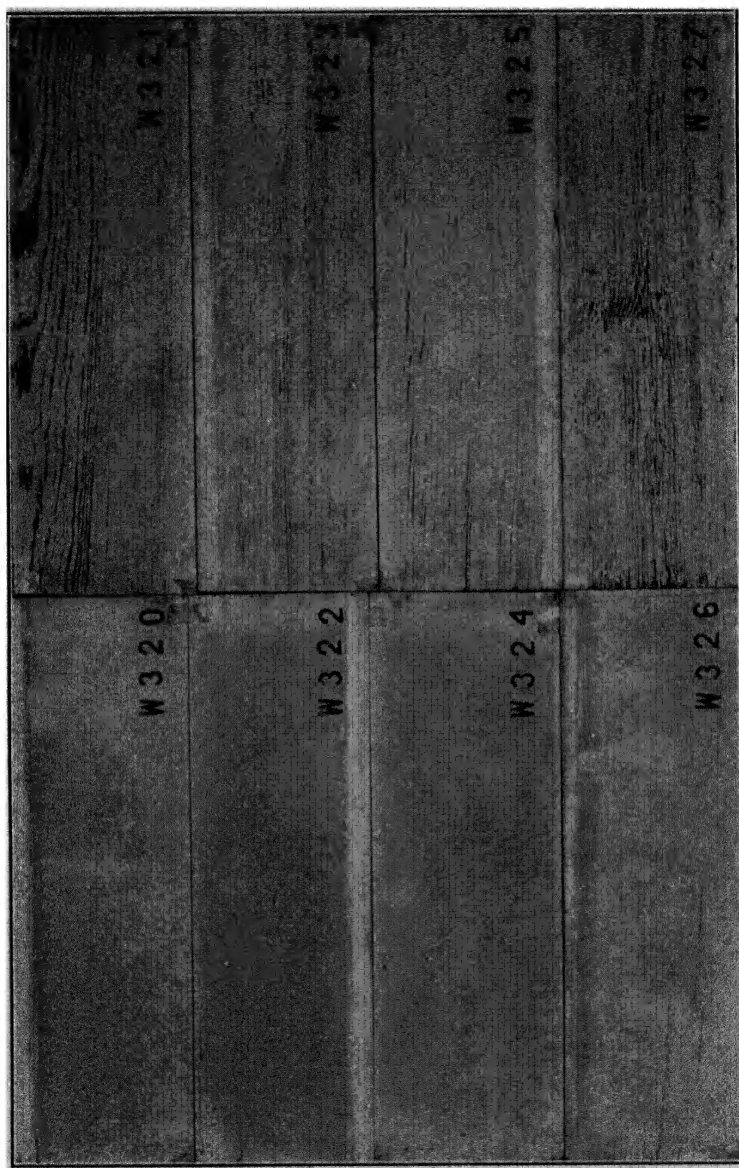


FIGURE 69. Comparison of aluminum primer and white primer on shortleaf yellow pine; 4 panels on the left have aluminum primer and 4 panels on right have white primer; 2 top coats of white paint on each panel; photograph taken after 18 months' exposure at New Kensington.

tices.^{20, 10} Blistering and paint peeling are commonly caused by excessive moisture penetration from the back of the lumber. In new houses, this moisture condition can be produced from the drying out of the plaster, particularly when the house is winter-built and the doors and windows are shut and heat is supplied for the drying process. The evaporated moisture passes through the walls and, if the weather is cold enough, may condense in the wall or against the back of the siding. A period of warm sunshine falling on the side of the house will then cause blistering because of the rush of water vapor against the back side of the paint film. Defective details of building construction may

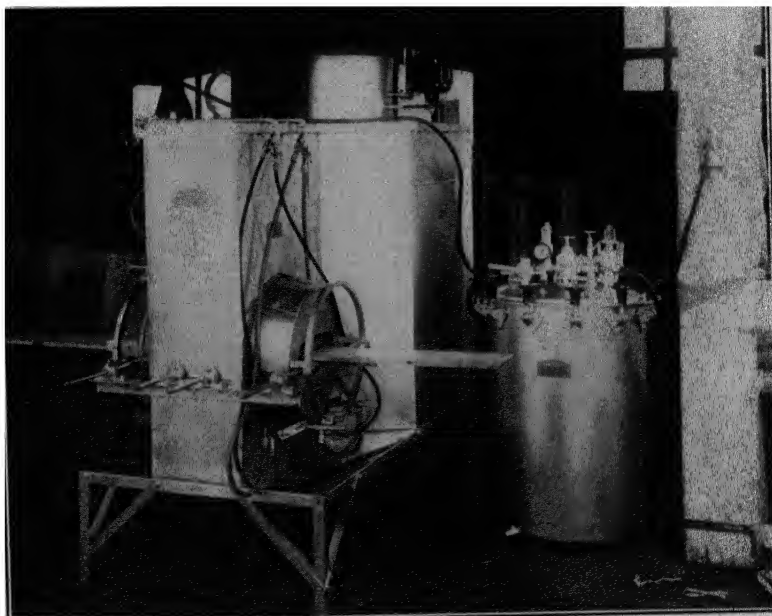


FIGURE 70. Equipment for mill priming lumber with aluminum paint.

permit entrance of water behind the siding and cause paint failure in localized areas. Common examples of this are seen around doors and windows which are not sealed or provided with suitable flashing; at the corner trim, where rain gets in behind the siding, or where leaking eaves and gutters let water through. Where these conditions are bad, the only remedy is to repair the building so as to prevent the entrance of water. Where a house has a record of early paint failures, some such causes as these should be looked for.

These ill effects of moisture could be eliminated if it were possible to seal lumber completely, both front and back, by painting.²⁰ It is not usually practical from the economic standpoint, however, to apply more than one coat of paint to the back of house siding. Fortunately, how-

ever, one coat of aluminum paint on the back has been found to be of practical service particularly along the sea coast and in climates where moisture conditions are adverse. In spite of the fact that one coat of aluminum paint offers only limited protection against long-time moisture penetration, it apparently slows up the rate so much that the tendency to peel and blister is greatly reduced. This is no cure-all for defects in building construction, and where water leaks in, around and behind

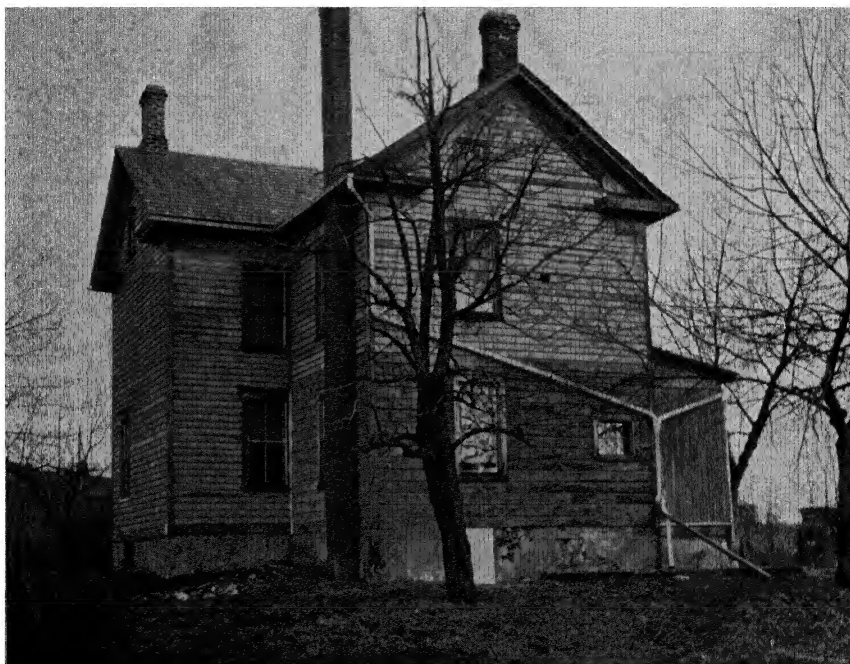


FIGURE 71. Photograph of house at Oxford, N. J., before repainting.

siding, the source of moisture should first be blocked by suitable building repairs. Aluminum paint, however, offers substantial protection against incidental moisture and has proved its merits in service.

Painting the ends of lumber is well worth while to seal the very porous end grain and stop wood checking and splitting, which are all too prone to start at this point. Back painting is coming back into favor, therefore, as a result of practical successful experience with this practice.

Mill Priming.

Mill priming is the coating of lumber on all sides, front and back, edges and ends, at the mill. Mill priming of lumber offers a commercial solution to the problem of back painting. It also offers a number of

additional advantages. Lumber can be spray painted at minimum cost when handled in suitable equipment. The customary plan is to pass the lumber on a conveying system, through a chamber in which a group of air guns direct a spray of paint at the lumber from all angles, so as to uniformly coat the wood. The excess paint drains into a sump and is re-used. The painted lumber is then air dried on racks or force dried in ovens.^{25, 30, 12}



FIGURE 72. Photograph of house shown in Figure 71 after being given one spray coat of aluminum paint and trimmed in dark green.

One of the foremost advantages of mill primed lumber is that it is protected during storage, shipment and installation, against rapid change of moisture content. Wood checking and splitting before painting are minimized or eliminated by this procedure. After siding has been applied to the house, it is a frequent experience to have it well soaked by rain before it is primed and painted. If the siding has been mill primed with aluminum paint, it stands such treatment without injury and requires only a short drying period before top coats can be applied. During service, the advantages of back painting inherent in mill primed lumber become apparent. In the case of the test fence described on page 158, it was observed that the joints between strips of siding mill-primed

with aluminum paint remained tight and sealed with paint. On the sections painted with white paint, after erection, the joints generally opened up, presumably because of expansion and contraction, causing creep of the lumber. In some cases as much as $\frac{1}{4}$ inch of unpainted wood was exposed at joints, in this way, and provided sources of entry for water and further wood deterioration.

Despite its proved technical merits, the idea of mill priming of lumber has made slow progress. This has been in part the result of economic

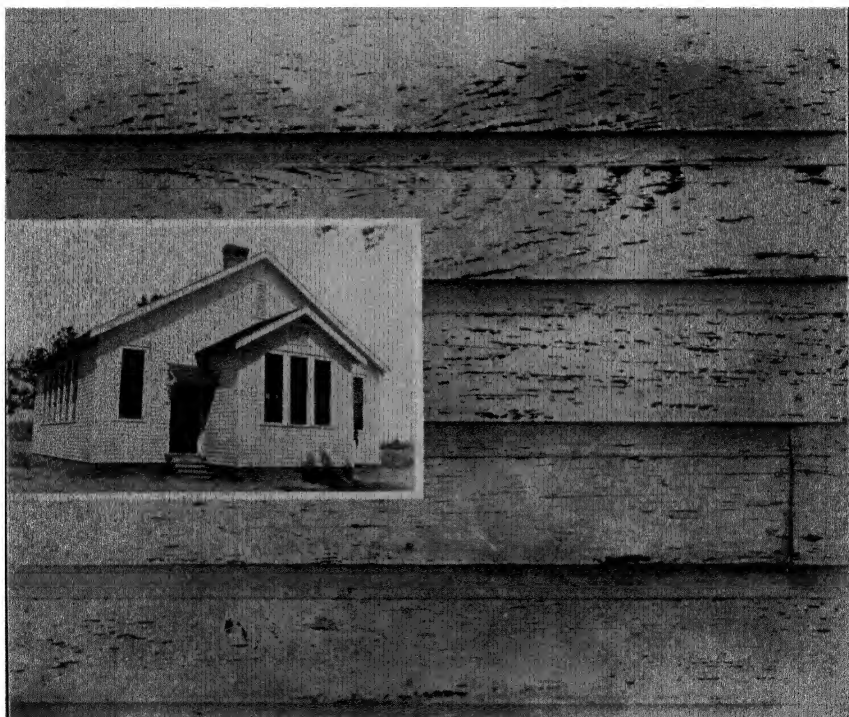


FIGURE 73. Thompson School, Walton County, Georgia; southern yellow pine finished with two coats of white paint; photo taken about $3\frac{1}{2}$ years after painting.

conditions in the last five years. It would seem, however, that the lumber industry, competing with other building materials, must eventually adopt mill priming, at least for certain grades of lumber. Perhaps the demand will have to develop by education of the consumer to the merits of lumber mill primed with aluminum paint. Already, several lumber manufacturers have mill primed southern yellow pine and made it commercially available. A number of progressive manufacturers of wood products, such as window frames, etc., are also selling their products with a coat of aluminum paint.

Aluminum Paint in Service.

The results of laboratory tests are fully confirmed in actual practice by the service given by aluminum paint used either as a primer or for both top coats and primer. Only a few striking examples will be cited for purposes of illustration.

In Figure 71 and 72 are shown a frame house before and after applying one sprayed coat of aluminum paint. While one coat of aluminum paint does not offer extended protection, nevertheless its ability to hide

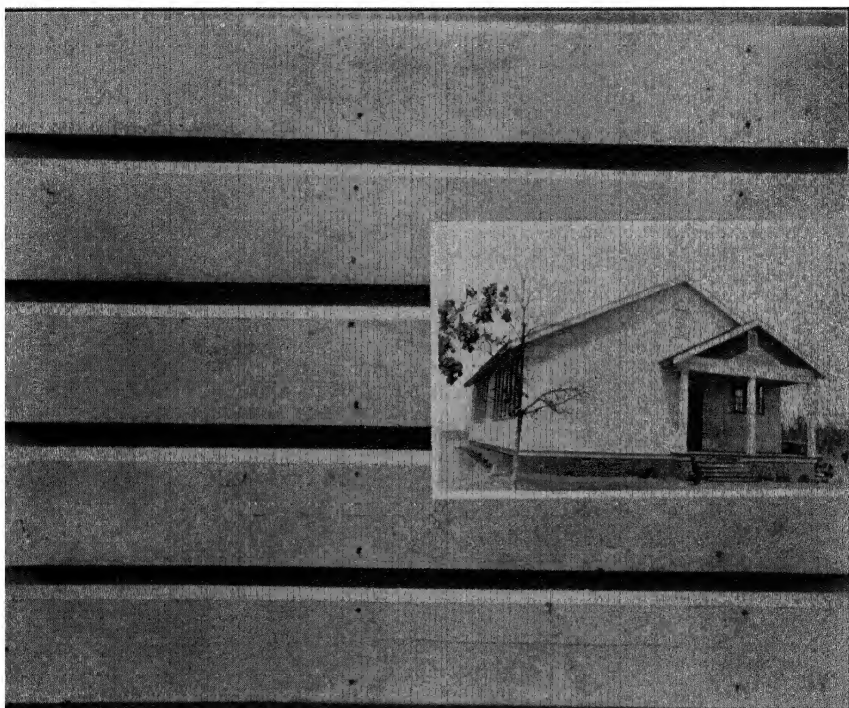


FIGURE 74. Peters School, Walton County, Georgia; southern yellow pine mill-primed with aluminum paint followed by one coat of white paint after erection; photo taken about 3½ years after erection.

and cover is demonstrated by these two photographs. As a result of the excellent service obtained on this house, a substantial program of repainting houses with aluminum paint was inaugurated at this location.

To prove for themselves the merits of aluminum primer, the school authorities in Walton County, Georgia, made a test on two new frame schoolhouses. Southern yellow pine siding was employed in the construction of both schoolhouses, and on one, Fig. 73, the wood siding was finished with two coats of white paint. The siding on the other schoolhouse, Fig. 74, was mill primed with aluminum paint before erection;

it was then given one finish coat of white paint. The schools were erected and painted in the summer of 1930; the photographs were taken in March, 1934. The inserts in the figures show general views of the schoolhouses, and the closeups of the siding illustrate clearly the condition of the paint about four years later. Flaking and peeling of the white paint on the white-primed siding has proceeded to the point where the protection is gone and the appearance quite unsatisfactory. The white paint, however, applied over aluminum primer, was still in good condition, as shown in Fig. 74. It may be noted that the trim on this school had received no aluminum primer and was given two coats of the white paint; after 4 years' service it was in the same poor condition as the white paint on the other school.

Wray has reported on an inspection of 300 houses in Tennessee, 188 of which were painted with aluminum paint for both primer and top coats, and a small number of which were primed with aluminum paint, following by a coat of white paint.³¹ The service rendered by aluminum paint, either as primer or as primer and top coat, was quite striking. Each year finds new evidence accumulating of the merits of aluminum paint in the protection of wood.

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Chapter 8

Aluminum Powder in the Arts

A major part of this monograph has been devoted to the use of aluminum powder in paint because of the widespread interest in the subject. Aluminum powder also has important uses in other arts, such as in printing, coating of paper, coating of balloon fabrics, the manufacture of fireworks, and aerated concrete, to mention only some of the most important applications. Aluminum powder, in addition to its obvious uses as a pigment, can enter into certain chemical reactions which have interesting applications. An example is the well-known "sparkler," which is so much in evidence on the fourth of July.

Aluminum Powder in the Printing Art.

The oldest method of applying bronze powders is to print the design in ink or size and then dust the bronze powder over the surface. The metallic powder adheres to the inked areas and gives a bright metallic surface; the excess powder is dusted off. The powder can be applied by means of a wad of absorbent cotton or sheepskin, dipped in the powder and then tapped lightly against the inked area. The sheets are next stacked until the ink has set. The excess powder can then be dusted off and rubbed off.

The characteristics of the ink or size will be determined in part by the character of the surface to which it is to be applied. The hiding power of the aluminum powder is sufficiently high so that it will generally conceal even a colored ink. Usually it is better to print with a white or unpigmented ink or size. The ink should not, of course, offset upon sheets piled against it, and should have sufficient "tack" to hold the aluminum powder when it is dusted lightly against it.

Special grades of powder, known as Litho powder, are made for this bronzing; they have a minimum of polishing agent on the surface so that they will not stain or adhere to the uninked areas of the paper. The grade of powder used will depend upon the effect desired. Extra Brilliant Litho powder contains some relatively large aluminum flakes which give a marked luster and brilliance to the powder. However, the finer grades give a much smoother appearing film.

The paper selected for bronzing should preferably have a surface of such character that it itself will not retain the bronze powder. Smoothness is the principal requirement in this respect. However, with a little care in the cleaning operation, almost any paper can be used. It is so

easy to make a practical test that no further discussion of this point is necessary.

When bronzing operations are carried out on any substantial scale, suitable equipment should be provided. Automatic bronzing machines are equipped with dust-collecting devices to retain the excess bronze powder which would otherwise be lost. They eliminate the dust nuisance and, if properly made and operated, the danger of explosions from dust and air mixtures. All metal parts should be given a good electrical ground connection. The equipment should be frequently and rigidly inspected from the safety standpoint to make certain that sparks, electrical or otherwise, cannot occur and ignite an explosive dust mixture.

Aluminum Printing Ink.

Aluminum powder may also be used as a pigment in printing inks. It requires somewhat different handling than non-metallic pigments in order to give the best effect. Printing inks, as a class, are quite similar to paints and varnishes in their make-up. However, they must have their consistency and drying time adapted to the special conditions of printing. Linseed oil and chinawood oil are the most important constituents of the better grade inks. They are bodied and made into a varnish-like liquid by heating in kettles, just as previously described for paint vehicles. Other ingredients, such as gums, rosin, rosin oil, and the like, may be incorporated, depending on the kind of ink which is being made. Metallic driers of the lead, manganese and cobalt type are incorporated in the finished ink, together with the desired color or pigment.

A straight bodied linseed oil varnish was formerly used for aluminum ink. Now most manufacturers use chinawood oil (or perilla oil) as a base for aluminum inks. Cobalt linoleate is a commonly used drier. The increasing use of aluminum ink in printing has led to the development of satisfactory vehicles, generally available from ink manufacturers. The aluminum pigment is mixed with the base by means of a knife or spatula, and is not ground in the ink as are the non-metallic pigments. Where ink has to be mixed frequently or in substantial volume, a mechanical mixer of the pony type, for example, may be employed. As in the case of paints, the brightest ink is usually secured by mixing as needed. Some darkening may be experienced if the ink stands for very long after being mixed. That, however, is greatly influenced by the character of the powder or paste and the ink base with which they are mixed. Satisfactory mixed aluminum inks are commercially available. Another difficulty sometimes met with is excessive thickening or solidification of the mixed ink on long standing.

The amount of powder to be added will depend upon its fineness, the consistency of the base, and the kind of press the ink is to be used on. The consistency of the base is an important factor, for the thinner the varnish, the more powder it will carry. The consistency of the ink is in turn determined by the kind of press with which it is to be applied and

the kind of surface on which it is to be printed. On one particular job which was being run on a cylinder press, only 30 to 40 per cent of a certain Lining powder was used when the aluminum ink was applied over a sized impression, and about 20 per cent of powder when the aluminum ink was applied over two size coats.

Standard and Extra Fine Lining powders and paste are the grades of aluminum pigment most used for metallic inks. Because of the very thin film of ink on the printed impression, the coarser grades of powder do not hide and cover very well. A Lining powder of very high covering area is now available which gives excellent results with as little as 15 per cent of this powder in the ink base. Aluminum paste with a very fine mesh pigment of high covering area is being extensively used as pigment in mixing aluminum inks. The amounts of drier to be added should be carefully determined, as satisfactory drying of the ink has much to do with holding the powder firmly on the printed impression and minimizing its tendency to come off when rubbed. Aluminum ink, because of the leaf-like character of the pigment, dries more slowly than non-metallic pigment inks; the proper adjustment of the amount of drier to be added requires special attention for this reason. Too much drier, of course, will cause trouble from drying on the press, necessitating frequent wash-ups.

With regard to the press, the suggestion may be made that aluminum ink be transferred from fountain to type with a minimum of rolling and transferring. Excessive working on plate and roll may cause some balling up of the powder. This is in contrast to the action of non-metallic inks, where every effort is made to spread them out to a very thin film. It may be found necessary or desirable to use fewer rollers in transferring the ink. It may also be necessary to wash up more frequently than would be the case with non-metallic inks. Some aluminum inks have a tendency to pile up on rollers and printing plates and, if not removed, cause an irregular appearance in the impression. For these reasons more care is necessary in using aluminum ink on a cylinder press than on a job press. More powder can be used in job press ink and it is easier, in general, to secure a bright metallic impression with a job press than with a cylinder press. When some experience has been gained, however, work of a satisfactory character can be produced on a cylinder press.

The paper to be printed will determine many of the details of printing. The easiest paper on which to apply aluminum ink is a white coated paper with a glossy surface; a satisfactory effect can usually be obtained with one impression. Even though examination under a microscope discloses relatively large areas of white paper showing through between the aluminum flakes of the ink, this condition does not detract from the brilliance of the printed areas because of the intrinsically high reflectivity of the white paper. In fact, it may be said that as long as the spaces uncovered by aluminum flakes are not large enough to be detected by

the eye, they do not interfere with the brightness and metallic effect of the printed impression.

A somewhat different situation prevails where the ink is printed on a colored coated paper. If good covering is not secured, the paper may show through and give the impression a tinted effect. Nevertheless, a smooth coated surface, even if it is colored, takes aluminum ink so well that it is seldom necessary to give it a preliminary printing with size.

The problem of applying aluminum ink effectively becomes more complicated as the surface and texture of the paper becomes rougher and more open. With papers having a plated finish, it is generally desirable to print first with size. On colored paper the size coat is more effective if it contains some white pigment. A mixture of 1 part of white ink to 2 parts of size has been found to work well. A small amount of aluminum bronze powder can be added to the size coat. However, if too much powder is added the ink is likely to offset against the sheets piled on it. When the size coat has set to just the right degree of tackiness, the top impression of aluminum ink can be applied. The white pigment in the size probably helps to conceal the colored surface, but the principal function of the size coat is to give a smooth flat surface for the aluminum ink. Where the design is printed in more than one color, the color coat may sometimes be used as the size coat for the aluminum impression. It is still more of a problem to apply aluminum ink to papers having an antique finish. On these it may be necessary to use two size coats. The first impression may contain a little white pigment, and should be allowed 24 hours to dry before applying the second coat. The second coat of size can be applied without pigment, and after setting two or three hours to become tacky, the top impression of aluminum can be printed.

Aluminum ink will not give the best results on bond paper without a preliminary coat of size. With the size coat, excellent results are attainable.

The setting and drying of the aluminum ink impression can be improved and hastened by passing the printed sheet over a series of gas flames arranged to just touch the paper in passing. The tendency to offset is reduced in this way. In printing with aluminum ink on high-speed cylinder presses, spraying with wax, or a proprietary solution developed for this purpose, is sometimes employed to prevent offsetting. The solution is applied in the form of an extremely fine mist from an air-gun; it does not interfere with drying nor change the appearance appreciably.

The successful employment of aluminum ink requires a careful study in color contrasts and adaptation of the design to the printing characteristics of the ink. In general, the most effective results are secured when the aluminum ink is used in solid areas. Lines, if not too fine, may however be successfully used. The printer who formerly had difficulty in printing fine lines with aluminum ink or in printing black

or colors over aluminum now finds these problems largely solved with advances in ink manufacture and the technique of printing with aluminum ink. Other interesting suggestions regarding printing with aluminum ink have been published by Barrett,⁵ by Eney, Jr.,¹⁵ by Hoch,²¹ by Kline,²⁴ by Meyer,³⁰ and by Arthur.^{2a}

In printing wall paper, distemper or water colors are commonly used. The adhesive medium may contain starch paste, gum, and the like, mixed with water. Aluminum bronze powder can be effectively used in such a medium for decorating wall paper, but a special grade is necessary. In finishing the bronze powder, a polishing material must be employed which will permit uniform suspension and dispersion of the powder in the aqueous base without loss of color or objectionable reaction of the powder with the water.

Hot Stamping Process with Bronze Powder.

A printed or embossed impression having the appearance of burnished aluminum foil can be produced by a novel printing process requiring special equipment. In this method, known as the "roll leaf process," the aluminum bronze powder is carried on a transfer leaf. This leaf is a special glassine paper which has been coated with a thin layer of wax, followed by a very thin and uniform layer of bronze powder mixed with a binder and topped off with a coat of sizing material. This transfer leaf is made up into rolls and mounted in the press so that it feeds past the die. The brass die which carries the design is heated to a suitable temperature. At each impression the hot die presses the transfer leaf against the paper which is being stamped or embossed, and the film of bronze powder is transferred to the paper. After each impression the roll leaf is automatically advanced the width of the die to bring a fresh area into position. The bronze powder film is only transferred where it is pressed by the hot die. The unused area of the film is wasted. All kinds of bronze powders and non-metallic pigments can be applied by roll leaf. A metallic aluminum impression can be produced by "bronzing" or printing with aluminum ink. More details of the process can be obtained by consulting some of the patents on the subject of metallic transfer mediums.^{6, 9, 18, 22}

Metallized Paper.

Metallized paper is available with an aluminum finish. It is produced in several different ways. The most widely used method makes use of a mixture of aluminum bronze powder with a casein adhesive. Since the regular paint grades of aluminum bronze are not easily wet with water, special water-miscible grades of powder are produced for this particular application. The special powders have lower grease content and are specially prepared for the purpose. The mixture is applied in a thin film to paper and the process is made continuous by the use of paper in rolls. The paper first passes under a large revolving brush

wet with the coating mixture and then comes in contact with a series of vibrating brushes which smooth out the brush marks from the coating roll. From the coating machine the paper passes into a drying room heated to a temperature of 110° F., where it is held in large loops in drying racks until thoroughly dry. It is then rolled up at the other end of the drying room and in many cases is returned to the machine for a second coat. The paper is then passed through heated rolls known as calendering rolls, which smooth out the finish and burnish it to a high luster. The paper may be sold in this form, or may be given various artistic finishes by embossing.

Aluminum-coated papers are also produced using Lining grades of aluminum powder mixed with lacquer vehicles. This type of coating is usually applied by pouring on an excess of the aluminum lacquer and permitting it to be wiped off by passing the paper under a straight edge or "doctor blade." This finish, while more expensive than the casein coating, is more water resistant.

A third method, though very little used, comprises first coating the paper with a suitable adhesive or size and while this size is still tacky, the aluminum powder is dusted uniformly on the paper in special bronzing machines and the excess wiped off with badger or rabbit-hair brushes. While such a coated paper has good brilliance, difficulty is experienced with the powder dusting off unless a clear coating is applied over it by a subsequent operation.

Along an entirely different line, novel effects can be secured by incorporating aluminum flakes in the pulp during the paper-making process. The Strathmore Paper Company has made such a paper, which is called "Silverflake." The flakes are relatively large, some as much as a millimeter in diameter, so that they appear as bright metallic specks in the paper. Other flakes, beneath the surface, have a shadowy appearance which adds a distinctive effect.

Colored Aluminum Powder.

Although aluminum metal cannot be colored by any small amount of alloying ingredient or otherwise, the aluminum flakes can be given a surface color by dyeing. In this way a series of very brilliant powders can be produced which are used for decorative purposes, sign painting, etc. In order to dye aluminum bronze powder, it is first necessary to remove from the surface of the flakes any greasy substance which has been introduced in the stamping process, and leave the surface with an oxide or mordant film which will absorb enough of the dye to color it. It is then immersed in a solution of the dye, and the dye solution evaporated on the powder. Typical dyes which are used are—auramine, chrysoidine, fuchsine, rhodamine, saffranine.

Smalley⁴¹ has given many interesting details regarding the dyes used and the technique of their application. Von Schlenck⁴⁶ recommends treating the powder with a 10 per cent alcohol solution of tannic acid

in order to clean and mordant the surface, after which the powder is dried. The powder may also be treated with a boiling 0.5 per cent solution of alum. It is then mixed with an alcoholic solution of appropriate dye and evaporated to dryness with agitation in order to uniformly coat the flakes without their sticking together. Skill and experience are necessary to produce a satisfactory product.

The dyed powders are limited in their application by the fact that none of them are absolutely fast to sunlight; this limitation is more or less serious, depending on the particular dye employed and the conditions under which the powder is to be used. For the general class of work on which they are to be used, they are quite satisfactory. The colors available include crimson, cerise, gold, brown, violet, blue, emerald green, turquoise blue, etc., in the most brilliant and attractive shades.

Aluminum Powder in Plastics.

Certain grades of aluminum Lining powders are used to obtain decorative effects in molded plastics. These plastics, of which Pyralin is an example, are in many instances pigmented to obtain certain decorative color effects and various degrees of transparency. When aluminum powder is used as a pigment for this purpose, a decidedly pleasing and novel effect is produced. With the particular method employed to introduce the powder into the plastic mass, the powder flakes in different areas assume different orientations, reflecting light beams in as many different directions. This produces what might be termed a silky appearance somewhat similar to the moire effect obtained by water-processing silk. The appearance is also suggestive of mother-of-pearl. The appearance of the article changes according to the angle at which it is viewed with the eye, each new position bringing into play light reflections from a new combination of bronze powder flakes. This effect is further enhanced by dyeing the plastic or using dyed aluminum bronze powders, or both. Films or sheets made from cellulose derivatives may be given novel decorative effects by the addition thereto of coarse flakes of aluminum powder, or by more heavily pigmenting with a finer grade of powder, a material resembling aluminum foil is produced.

Metallics.

For decorative purposes a special grade of flake aluminum is made, which is sometimes referred to as "metallics." Metallics consist of coarse aluminum flakes between about 10 and 16 mesh in size. In metallizing a surface it is coated with glue or varnish, and while the surface is tacky the metallics are dusted on. It is a bronzing process quite similar to that used in lithographic printing.

This powder can be used in Christmas decorations to give a bright and scintillating surface, or in show window dressing.

Aluminum Powder in the Aircraft Industry.

Aluminum bronze powder is almost indispensable in the fabrication of durable balloon fabrics. The gas-retaining properties of these fabrics are given by the thin films of rubber contained between the plies. Without protection from sunlight, these thin films of rubber, about 0.1 mm., more or less, in thickness, are subject to excessively rapid deterioration. Even the cotton fabric itself suffers from sunlight. A top coating of aluminum powder on such a fabric affords protection from sunlight with minimum increase in weight.

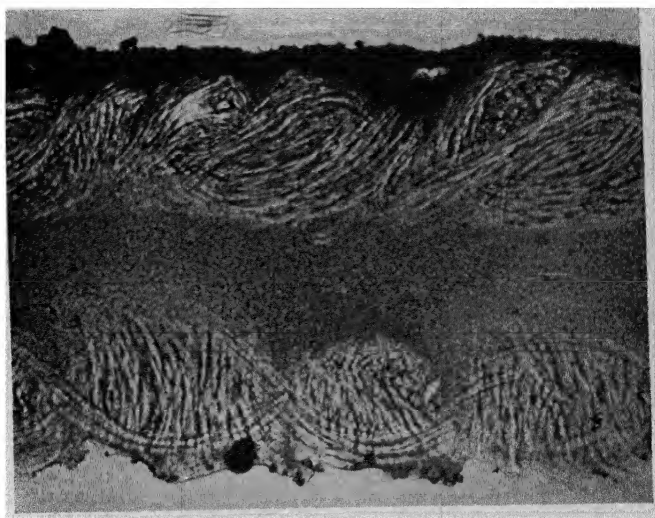


FIGURE 75. Photomicrograph of thin cross-section of 2-ply balloon fabric with aluminum pigmented rubber coating on upper surface.

In Figure 75 is shown a thin cross-section of a two-ply balloon fabric, which illustrates the construction. The two plies of cloth are shown with a relatively thick gas-retaining film of rubber between them. One ply is laid on a bias of 45° ; this is shown in the illustrations by the variation in the angle at which the threads in the warp and filling of each ply are cut. On the outside is seen the thin, opaque coating of pigmented rubber which protects the rubber and fabric beneath. It is this top coating which contains the aluminum powder protection. A thin film of rubber, scarcely noticeable in the picture, is also provided on the inside surface of the fabric.

The gas-retaining film must be spread with skill and perfection, for it is very thin, frequently not over 0.1 mm. thick, and yet it must be applied in twenty or more separate coats. It has been proposed to incorporate aluminum powder in the gas-retaining film in order to

decrease its permeability to gas.¹³ The two-ply fabrics weigh from 9 to 12 ounces per square yard. For large airships of the dirigible type, heavier three-ply fabrics are frequently employed.

The rubber compound before application is in the form of a dough, made by kneading rubber, sulfur and other compounding materials with solvent. The dough is applied by means of a machine known as a spreader, in which the fabric is drawn between a roll and a knife which scrapes off the excess compound. For the top coats, aluminum powder is mixed with the dough. The color of aluminum powder is unaffected

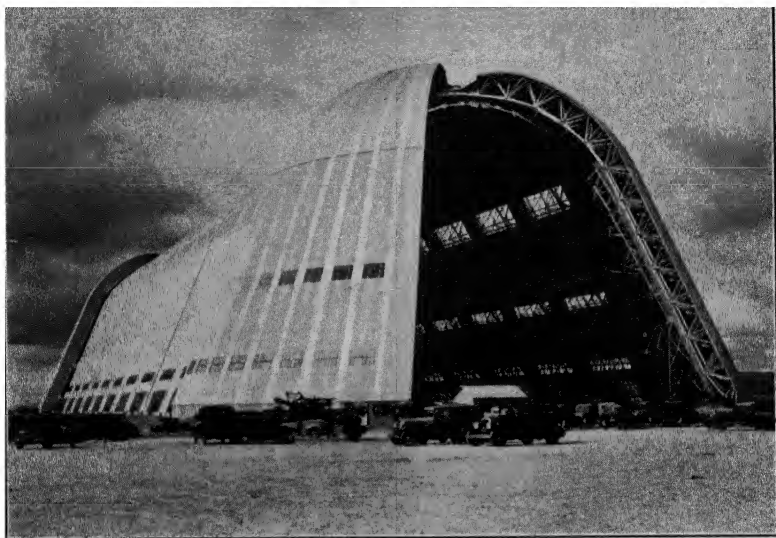


FIGURE 76. U. S. Navy Dirigible Dock, Sunnyvale, California, painted with aluminum paint. In the construction of this dock, a million board feet of mill-primed lumber were used.

by the sulfur employed for vulcanization, which is fortunate. Where an extra bright coating is desired, the top coating may be lightly dusted with aluminum powder.

Another method which has been used in applying the aluminum coating is to make a thin rubber cement containing the aluminum powder and print it on the fabric. In this method an engraved steel roller picks up a thin film of the aluminum-rubber compound and transfers it to the fabric. This method of application minimizes the difficulty, which may be experienced with the spreader, of getting thin coats on the seams.

Aside from the protection it offers to the rubber, the aluminum coating is valuable for the thermal protection it gives to the gas envelope of a balloon or airship. By reflecting a large proportion of the sunshine, it minimizes temperature changes. For this reason an aluminum coating

is applied even to rigid airships where the outer envelope is not rubberized nor does it have to be gas-tight. Aluminum paint with either varnish or pyroxylin vehicles is used for the purpose. It helps preserve the fabric because of its opacity to sunlight. Similar use is made of aluminum paint on the fabric covering of airplane wings.

A unique application of aluminum powder is in the navigation of aircraft. Pan-American Airways, Inc., uses bombs filled with aluminum powder, which can be dropped from a plane onto the surface of the ocean. The powder from the broken bomb spreads out, leafs on the water, and provides a brilliant spot which serves as a visible marker in measuring the drift of the plane.

Aluminum Powder in Rubber Compounding.

Aside from the field of balloon fabric, aluminum powder has other uses in combination with rubber. Some manufacturers of solid rubber truck tires incorporate aluminum powder in the rubber stock next to the steel rim. The aluminum powder is used to increase the thermal conductivity of the rubber compound and hence facilitate the cure of the interior of the tread rubber. According to Webster Norris,³² a commonly used formula for solid tire rim base stock comprises:

Smoked sheet rubber.....	36.0%
Lime	18.5
Sulfur	36.5
Aluminum powder	9.0
	<hr/>
	100.0%

Norris also gives a formula for steel rim cement containing aluminum powder.

Aluminum powder is used in rubber dental plates in sufficient amounts to give a metallic luster to the cured dental plate.

Aluminum powder and also the powder colored by dyes have been used for decorating a variety of articles made of rubber, such as bathing caps, rain coats, toy balloons, etc. The aluminum powder has, of course, the great advantage of not tarnishing in contact with sulfur. Norris outlines three methods for such applications:

1. The aluminum powder may be incorporated in the rubber mixing to the desired color. If for molded goods, the stock should be dusted with the metallic powder before being placed in the molds.

2. If the mixing is for dipped goods the metal may or may not be in the rubber mixing but before or immediately after acid curing the article should be dusted with powder of the desired color.

3. After vulcanization and before removal of the dipped article from the form it may be coated with a thin rubber cement and the metallic color be applied upon the wet cement.

Gibbons¹⁷ has patented a process for producing rubber sheet with a brilliant metallic surface which includes dusting a uniform layer of aluminum bronze powder over the surface of the unvulcanized stock, then placing a sheet of metal foil over the powder-coated stock and passing it through rolls to press the powder into a smooth, flat surface, after which it is vulcanized in the usual fashion.

Denmire¹¹ has patented an air bag such as is used in vulcanizing pneumatic tire casings which has a substantial proportion of aluminum powder incorporated in the outer layers to give it a very smooth surface and one which minimizes adhesion of the tire casing. It retains a smooth surface and hence does not readily transmit defects to the inside of casings being vulcanized in contact with it.

Pyrotechnic Uses of Aluminum Bronze Powder.

Aluminum bronze powder is used in the manufacture of sparklers and other pyrotechnic articles. The sparkler is made from a mixture of aluminum powder and a nitrate, together with steel filings. The combustion of the aluminum powder-nitrate mixture raises the steel filings to the ignition point, and they burn with a shower of bright, scintillating sparks. The sparks themselves are about as harmless as a shower of sparks from steel held against a grinding wheel. The end of the sparkler is, however, of appreciable size and at a very high temperature, and hence not to be touched with impunity.

In making sparklers, the ingredients—for example, aluminum powder, steel filings, barium nitrate, and an adhesive such as dextrine—are mixed into a thick paste with water. The steel wire, which is to form the base of the sparkler, is dipped into the paste and coated with it for perhaps half its length, after which the paste is dried on the wire. A grade of unpolished powder is used for sparkler manufacture.

Another use of unpolished aluminum powder is in the manufacture of star shells and flares. The aluminum powder burns very rapidly and with a bright white light. In colored flares, the amount must be limited in order not to mask the color. The rate of combustion can also be controlled by using mixtures of aluminum powder with a coarser grained aluminum or atomized aluminum.

Flashlight powders consist principally of powdered magnesium but aluminum powder is frequently added to modify the actinic properties of the light and control the rate of burning of the powder mixture. The duration of flash is shortened by increasing the proportion of magnesium or decreasing the particle size.

Experimentally, at least, aluminum powder has been used as a constituent of liquid oxygen explosives. In this type of explosive, a cartridge of combustible material, such as lampblack, is saturated with liquid oxygen. It has the advantage that in case of a misfire the oxygen eventually evaporates and the cartridge is therefore harmless. Perrott⁸⁷ says that experiments in the Bureau of Mines have shown—

"that a cartridge containing only aluminum powder and a small quantity of diatomaceous earth may be detonated, giving a true explosion, and showing a slightly greater ballistic effect per unit volume than a cartridge of lampblack. The boiling point ⁴⁰ of aluminum oxide is 2210° C. at atmospheric pressure, and it is reasonable to suppose that gaseous Al_2O_3 is actually present. Calculated on this basis, the maximum ballistic effect theoretically obtainable with aluminum per unit volume of cartridge is 21 per cent greater than obtainable with pure carbon. A further effect of aluminum is the increasing of sensitivity to detonation of certain combustible mixtures. Addition of small quantities of carbene, naphthalene, petroleum oil, or gilsonite also increases sensitivity to detonation."

Baker and Strong ⁴ have made use of the high heat of combustion of aluminum in the operation of an oxy-aluminum blow torch. In their blow torch, a central oxygen orifice was surrounded by eight tips through which aluminum powder (6 per cent on 200 mesh) was fed into the flame. The flame burns quietly and is dazzling white in color; it gives off voluminous clouds of very finely divided aluminum oxide fume. A piece of molybdenum melted in the flame, indicating a temperature above 2500° C.; it would not, however, melt tungsten. As might be expected, considerable difficulty was experienced in feeding the powder uniformly enough to keep the flame burning steadily.

Thermit.

The so-called "thermit" reaction involves the reduction of various metallic oxides, by reaction with a granular metallic aluminum. The heat of reaction between aluminum and ferric oxides, for example, is sufficient to melt the reduced iron and heat it to a relatively high temperature. The reaction is extensively employed for preparing carbon-free metals and alloys. Another far-reaching application has also been made in welding; it provides a convenient means of producing large or small quantities of clean, superheated iron or iron alloy, at the point of the weld.

Grained aluminum, which consists of more or less spherical particles of aluminum of substantially larger volume than the flakes of aluminum bronze powder, has been generally used for the thermit mixture. However, under some conditions where it is desired to change the speed of reaction, a certain proportion of aluminum powder may be incorporated in the reaction mixture. Aluminum powder from 10 to 20 mesh in size is suitable for this purpose.

Chemical Uses of Aluminum Powder.

An important chemical use of aluminum powder is in the recovery of gold and silver from cyanide solutions. In the cyanide process of treat-

ing gold and silver ores, the finely pulverized ore is leached or agitated with a weak solution of sodium or potassium cyanide to dissolve the precious metals. The clear solution is then treated to precipitate and recover the gold and silver. Zinc shavings or zinc dust have been commonly used to precipitate the precious metals. Aluminum has also been successfully used; powder made with a minimum of grease is being used for this purpose.

Alum for the paper-making trade is made by the solution of alumina from bauxite in sulfuric acid. Although the low-iron bauxite is used for this purpose, some iron goes into the solution. As ferric iron, its presence in the alum is quite objectionable because of the color. The iron can be readily reduced to the relatively colorless ferrous form by the addition of aluminum powder to the acid solution.

Aerated Concrete.

J. W. Aylsworth and F. L. Dyer^a conceived the idea of making light and porous concrete by blowing it full of gas bubbles and permitting it to set or harden in this condition. For the gas bubbles, they depended on the evolution of hydrogen by the reaction of aluminum powder with water and weak alkali. The process simply involves making a mixture of Portland cement, sand, or other suitable aggregate, aluminum powder and water, filling it into a form or other mold and allowing it to expand and set. The alkali content of the Portland cement may be sufficient to cause the gas evolution to proceed at a suitable rate, or a controlled amount may be added.

Such a process has been commercially developed and applied on a substantial scale both in Europe and in the United States. The outstanding characteristics of aerated concrete are lightness, high thermal and acoustic insulating properties, and resistance to damage by heat and flame. Its principal uses in building construction have been for floors, floor fill, roof, ceiling and partition slabs. In one instance, the lightness of construction possible with aerated concrete permitted the addition of six instead of four extra stories to an existing 7-story office building.

Manufacture of Aerated Concrete.

The manufacture of aerated concrete is a relatively simple matter once the technique is developed. The principal requirement of the aluminum powder is that it shall be substantially inactive when mixed with the cement before the addition of water, and after the concrete mix is made, the aluminum powder should react with the water and the free lime of the cement to produce hydrogen. The evolution of hydrogen should be gradual and yet complete, so that the mixture is uniformly expanded with small gas bubbles, which cause it to swell to about twice its usual volume and give a porous, sponge-like texture. A special grade of powder is manufactured for this purpose.

The mix used for aerated concrete will, of course, vary with the properties desired in the finished product. The product can be manufactured in precast form in weights as low as 25 lbs. per cubic foot, although in the field, the practical range is from about 40 to 90 lbs. per cubic foot. Stone concrete ordinarily weighs about 140 lbs. per cubic foot. The lightest material is usually made with cement alone

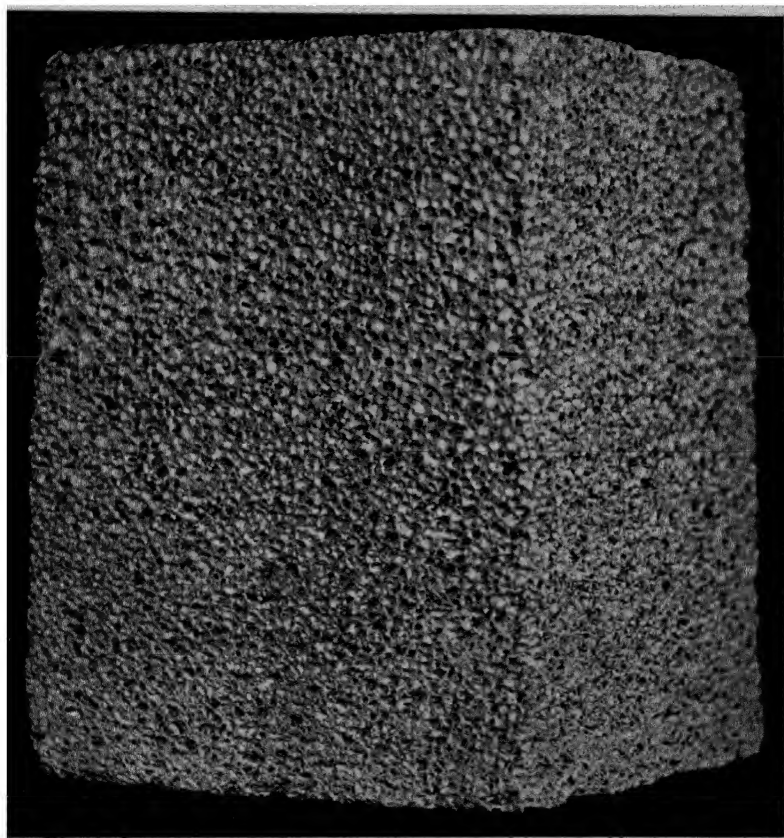


FIGURE 77. Block of aerated concrete.

and for heavier products, cinders, mixtures of sand and cinders, sand or slag are added to the cement. A typical mix consists of 10-mesh cinders and cement in the ratio of 40 to 60, with 0.10 per cent (1.0 pound per 1000 pounds of mix) of aluminum powder. The amount of aluminum powder to be added may vary somewhat with the brand of cement employed and the character of the product desired. In order to accelerate the action slightly, the mix should be kept at a temperature of 85° to 95° F. The cement and the aluminum powder should

be mixed dry, the water added, and finally the accelerator if one is employed. The mixture should be just wet enough to flow down the trough of a concrete mixer by gravity. After mixing, the concrete should be transferred to the forms as promptly as possible to minimize the loss of gas. Care should be taken to avoid any unnecessary agitation after spreading in the forms, so as not to interfere with the expansion of the material. It can be filled into forms for making blocks, or it can be cast in slabs of various shapes and sizes. In filling forms, it should be placed to a depth of only about 8 to 10 inches at a time in order not to interfere with the gas-expanding process. After one layer has set, another can be filled in on top after a period of 2 to 4 hours. The expanded or aerated concrete is allowed to harden in the usual manner. The technique of producing aerated concrete presents no particular difficulties, but the various factors requiring control are such that experience is needed to produce uniformly satisfactory results.

Properties of Aerated Concrete.

The density and other properties of aerated concrete will, of course, vary with the character of the filling material and the amount of gas expansion. In Table 19 are given data on the weight per cubic foot of various building materials and their thermal conductivities.¹

TABLE 19.
WEIGHT AND THERMAL CONDUCTIVITY OF SOME STRUCTURAL MATERIALS

Material	Weight per cubic foot Pounds	Thermal Conductivity	Equivalent thickness from standpoint of Insulation Efficiency Inches
Corkboard	10	0.30	1.00 **
Aerocrete***	30	0.69	2.30 †
Aerocrete	40	1.06	3.54 †
Aerocrete	50	1.44	4.80 †
Aerocrete	60	1.80	6.00 †
Aerocrete	70	2.18	7.27 †
Brickwork (dry).....	132	4.00	13.33 ‡
Concrete	140	8.30	27.70 ‡
Cinder concrete	110	5.20	17.35 †
Gypsum .....	...	2.98	9.93 *

** Bureau of Standards.

*** Aerated concrete made by Aerocrete Corporation of America.

† Peebles, Armour Institute.

‡ Willard, Lighty and Harding.

* A. S. R. E. Committee Report.

The compressive strength of aerated concrete will range from about 100-200 pounds per square inch for the lightest products to about 1000-1500 pounds per square inch for the mixtures weighing 70-80 pounds per cubic foot.

Aerated concrete is an excellent fireproofing material because of its substantial volume of voids and low thermal conductivity, coupled with good resistance to cracking or spalling when heated. Aerated concrete also has excellent sound insulating properties. In tests made by the National Broadcasting Company for the Aerocrete Corporation of America, a 4-inch slab of Aerocrete (45 pounds per cubic foot) was equal in sound attenuation value at 1000 cycles (42 decibels) to a 7-inch composite gypsum block slab comprising a 3-inch hollow block and a 3-inch solid block separated by a 1-inch layer of "Cabot's quilt."

Aerated concrete, made without sand or aggregate, has the advantage as a structural material that it can be cut by saw and worked with common wood-working tools. It holds nails quite satisfactorily. Its porous surface is exceptionally good for bonding cement and plaster finishes.

Aluminum Powder as a Lubricant.

Aluminum powder is not ordinarily thought of as a lubricant, although under some circumstances it may act as such. It has been used as an addition to mineral lubricating oils and given satisfactory results, although the observations still leave some doubts as to whether it effected any outstanding improvement in lubrication. Kocour²⁶ proposes to add aluminum powder to the grease used in wire drawing. He emphasizes the advantages of such use of aluminum in connection with the step of cleaning the drawn article in an alkaline cleaning bath; the adhering aluminum reacts to form hydrogen, which mechanically aids in dislodging dust and grease from the metal. The soft metal flakes should also help in lubrication under the heavy pressures existing in the die opening.

Canfield⁷ claims that a coat of lacquer containing aluminum powder and also graphite, dried on a hack saw blade, acts as an efficient lubricant when in contact with the work. A somewhat similar idea is expressed in a British patent¹⁴ which proposes to coat metal with an aluminum lacquer, followed by drying and drawing through a die. The aluminum helps prevent scaling during annealing and the wire or rod can be repainted as necessary during the drawing operation. Part of the aluminum remains as a thin adherent film on the drawn surface. Lowstutter²⁷ compounds a coating material of aluminum powder and finely pulverized boric acid, suspended either in water or a resin varnish. The clean steel is dip-coated in this mixture, and heated to 1450-1475° F. to drive off the volatile components and bond the aluminum to the steel. Thereafter the coated steel can be drawn or worked; the lubricating action of the aluminum is said to prevent any excessive working and hardening of the surface layers of metal.

Owen and Hewitt³⁴ claim that aluminum powder can be incorporated in the surface of a sound record to reduce advantageously friction and

wear between the sides of the grooves in the record and the reproducing stylus.

Mold Washes.

Substantial quantities of aluminum powder have been used in coating iron and steel ingot molds. Charles McKnight²⁹ has patented a mold wash for this purpose which contains aluminum powder as its essential ingredient. According to McKnight's method, a suitable mixture is made with 1 pound of aluminum bronze powder, 2 pounds of powdered graphite, and 1 pint of molasses diluted with water to a volume of 2 gallons. The wash is applied to the hot mold and when dry leaves a thin coating of aluminum and graphite on the surface. The users claim that this coating minimizes surface defects in the ingot, such as porosity, blowholes and oxide inclusions.

Alden² proposes a mixture of aluminum powder, molasses or sodium silicate, and kerosene; the mixture is steamed and then a small amount of tar is stirred into it to form a wash suitable for coating ingot molds. In 1903, Friese and Gilbert¹⁸ disclosed the general idea of using aluminum powder for mold coatings, particularly in the casting of brass.

Caulking Compounds and Cements.

Aluminum powder is being used in a variety of putties, cements and the like for its pigmenting characteristics; the product, when dry or set, has much the appearance of metallic aluminum. In a putty or caulking compound, the aluminum powder also helps protect the compound against drying out and becoming brittle and the deteriorating action of sunlight. Parr³⁶ has patented one such composition containing 1 to 50 per cent of whiting, 1 to 20 per cent of asbestos, 1 to 30 per cent of aluminum powder and enough oil and thinner to make it a workable plastic mass; it is marketed under the trade name, Alumi-lastic Compound. In grades of different consistencies it is being used for such a variety of applications as glazing windows, caulking joints, in many types of building construction or sealing seams in railway coach, motor boat and bus construction. Another composition is that of Haas¹⁹ which contains ground mica, talc, aluminum bronze powder and varnish.

Adhesives, such as the nitrocellulose type sometimes known as "household cement," can be given a metallic appearance by the addition of aluminum powder. Such cements are sometimes referred to as cold solder, because of their metallic appearance.

Aluminum powder can be safely stirred into molten sulfur, somewhat above the melting point of sulfur. Such a mixture looks much like aluminum when it solidifies, and has been used to patch surface defects in castings where questions of strength are not involved. *Do not* mix powdered aluminum and powdered sulfur together and heat, as the reaction may become vigorous. Morris³¹ has proposed adding

plaster of Paris and borax to aluminum powder and sulfur to make a readily fusible cement.

Aluminum bronze powder is incorporated in transparent or translucent sealing wax to give various novel color effects. It is also used in decorating wax candles.

Compounds for automatically sealing leaks in automobile radiators and water-circulating systems are of many varieties. Some employ aluminum powder as one of the ingredients designed to plug a leak. George I. Ray³⁸ has patented such a mixture with aluminum powder, flaxseed meal, sulfur and soap. The flaxseed is supposed to lodge in the opening while insoluble aluminum compounds are forming to permanently heal the leak. Another similar compound⁴³ contains flaxseed meal, aluminum powder, dry sodium silicate and casein.

Aluminum Powder in Soap.

Aluminum powder is used in the production of aerated soaps. The reaction of the aluminum with alkali in the soap produces hydrogen, which is so finely distributed through the product as to be quite invisible, but which makes a light, voluminous, "floating" soap which can be readily pulverized. It is said that the addition of the aluminum powder improves the color of the soap,⁸ because of the bleaching effect of the liberated hydrogen. From 20 to 30 grams of aluminum are employed per 100 kilos of soap (.02 to .03 per cent). Knigge²⁵ also states that the aluminum powder should be practically free from copper if rancidity or black spots in the soap are to be avoided. Vohrer⁴⁵ recommends against preparing the soap by the cold method but states that the aluminum powder should be added to the soap when warm or even hot. This will insure complete reaction of the aluminum and avoid leaving any metal in the soap. When the soap is boiled, however, there is more difficulty in keeping the gas (hydrogen) in the soap where its aerating effect is desired. A discussion of the use of aluminum powder in soap has been presented by Smith.⁴²

Miscellaneous Uses of Aluminum Powder.

In the preceding sections most of the major uses of aluminum bronze powder have been outlined. Other important uses and some not so important should be noted before closing. These particular applications are mentioned because they are suggestive of the wide variety of applications of this versatile product.

A type of "drain pipe cleaner" is being marketed which consists of a mixture of dry sodium hydroxide (lye) and sodium carbonate with metallic aluminum. The mixture is shaken into a clogged drain which presumably contains water. The reaction between the aluminum and the alkali generates considerable heat and the vigorous evolution of hydrogen continually agitates the mixture. The combined attack is supposed to discourage any obstruction in the pipe. Aluminum filings

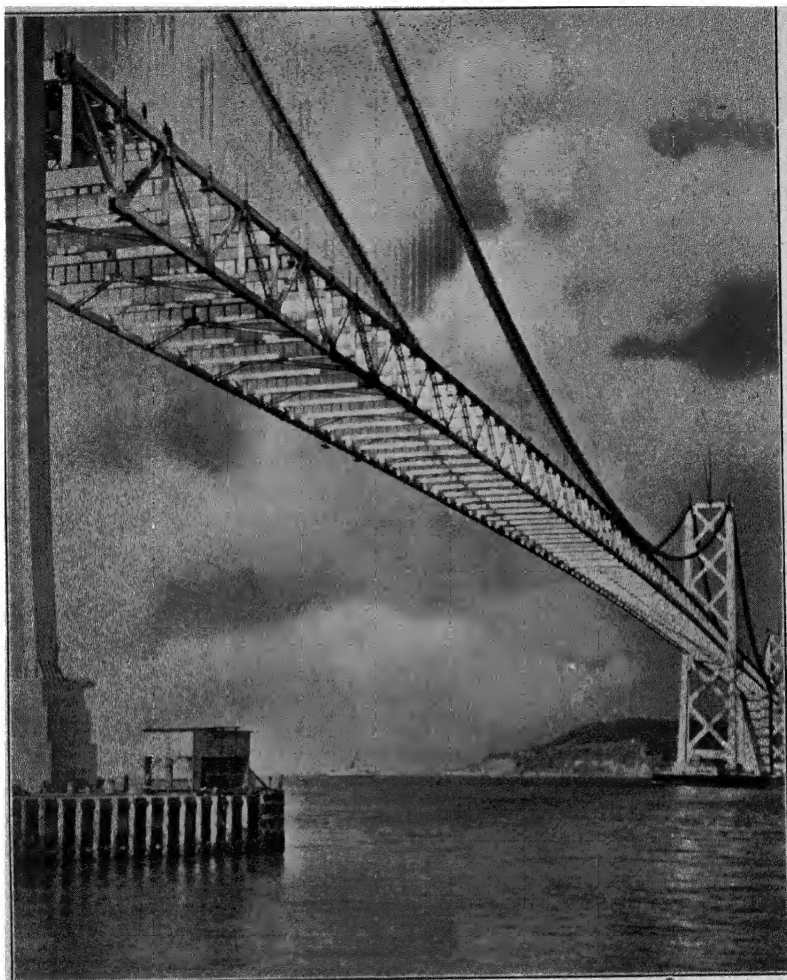


FIGURE 78. San Francisco-Oakland Bay bridge under construction and receiving a finish coat of aluminum paint.

and shavings are usually employed because of their low cost, but aluminum powder has also been used for the purpose.

Along this line, Sullivan⁴⁴ has patented an oil-well cleaning compound containing caustic soda, barium oxide, aluminum powder, sodium bicarbonate, soap powder, saponin and citric acid!

Aluminum bronze powder rubbed on a leather or canvas strop is said to aid in giving a fine edge to a razor. No quantitative experiments seem to have been performed in this field. However, Montgomery Waddell has gone so far as to patent a composition for rubbing on razor strops, which consists of cocoa-butter and aluminum powder.⁴⁷

In the motion-picture industry, aluminum bronze powder is widely used for coating projection screens. The aluminum powder may be applied in a paint or lacquer, or dusted over a tacky size coat. In the latter case, the coating is sometimes burnished by rubbing. A variety of patents covering various details of projection screen production include the use of aluminum bronze powder.^{10, 12, 20, 28, 33, 35, 48, 49} Mention might also be made of the high reflectivity of aluminum paint for actinic light, which suggests its use for many purposes where photography is involved. Aluminum powder is used by "screen" actors and actresses to simulate gray hair, to cite only one example. Dusted lightly on the hair, the photographic effect is very realistic.

The light-reflecting properties of aluminum powder are taken advantage of on roofing materials; in addition, the powder affords protection to bituminous materials from the deteriorating effects of sunlight and weather. Fleming,^{15a} for example, has patented a roofing material having a fibrous base, with a bituminous coating and aluminum powder adhering thereto. The metal powder is sprinkled on when the bituminous coating is warm and tacky.

Young⁵⁰ applies aluminum powder in a cellulose derivative lacquer over a bituminous coating on sheet steel. Robinson³⁹ makes a roofing material from compressed cork particles bound together and with a layer of aluminum powder adhesively bound to the surface.

Kappes²³ makes a light, porous fiber board with good heat- and sound-insulating properties by incorporating a small amount of aluminum powder and an alkaline reagent in the pulp or fiber mass. The reaction between the aluminum and the alkali produces minute bubbles of hydrogen which have a leavening effect upon the pulp mass.

Many of the uses of aluminum mentioned in this chapter are of minor importance from the standpoint of aluminum powder consumption. Some of the patents probably represent little more than an inventor's idea which so far has found little response from an unreceptive world. All of these uses, however, are convincing evidence of the versatile character of aluminum powder and the great variety of applications in which it is serving, aside from its major use as a paint pigment.

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Appendix

Specifications for Aluminum Paint Vehicles

The most efficient formulation of aluminum paint is obtained, as in the case of other paints, by careful selection and proportioning of the ingredients. In the final analysis, the criterion of quality is service, but the intelligent application of a variety of preliminary tests will assist in the selection of aluminum paint vehicles adapted for different services. Over a period of years, Aluminum Company of America has developed a number of specifications covering varnish vehicles for aluminum paint. These specifications represent the minimum requirements for good aluminum paint vehicles and will give generally satisfactory results. Many vehicles of extra quality exceed these minimum requirements, however, and afford sufficient extra protection and value to justify their higher cost.

Vehicle—Long Oil Varnish.

The vehicle for use on weather-exposed steel or other metals, brick, concrete and plaster, shall consist of a long oil varnish, made from ester gum, cumarone-indene, Amberol B1 or F7 or other suitable resins, together with suitable drying oils, and shall fulfill the following requirements:

- a. The varnish shall be clear and transparent.
- b. The viscosity shall be between 0.50 and 1.0 poise at 25° C. (77° F.), corresponding to Tubes A to D of the Gardner-Holdt Air Bubble Viscometer, if it is to be used with aluminum powder, or between 0.65 and 1.25 poises at 25° C. (77° F.), corresponding to Tubes B to E, if it is to be used with aluminum paste.
- c. The acid number of the vehicle shall be less than 15, based on non-volatile content of the varnish.
- d. It shall contain not less than 50% by weight of non-volatile oils and gums.
- e. It shall pass a 60% Kauri Reduction Test as described in Federal Specification TT-V-81, Paragraph F-2g.
- f. When thoroughly mixed with aluminum paste or powder in the proportion of 2 pounds per gallon of vehicle, the paint shall have good leafing quality, show satisfactory brushing and leveling properties and shall not break or sag when applied to a vertical, smooth, steel surface.

g. The *paint* shall set to touch in not less than 1 hour nor more than 6 hours and dry hard and tough in not more than 24 hours at a temperature of 20° C. (68° F.) to 30° C. (86° F.), except where it is to be used on brick, concrete or plaster, in which case the *paint* shall set to touch in 1 to 3 hours and dry hard and tough in not more than 18 hours at the same temperature.

Vehicle—Phenolic Resin Base Varnish.

This specification is designed to cover a long oil phenolic resin varnish of maximum elasticity and durability for use in making aluminum paint for all exterior applications.

a. The oil shall be vegetable drying oil as is necessary to meet the specification requirements. The volatile thinner shall be free from toxic hydrocarbons such as benzol. The varnish shall be free from rosin or rosin derivatives, as determined by the Lieberman-Storch Test.

b. It shall be clear and transparent.

c. The viscosity shall be between 0.50 and 1.0 poise at 25° C. (77° F.), corresponding to Tubes A to D of the Gardner-Holdt Air Bubble Viscometer, if it is to be used with aluminum powder, or between 0.65 and 1.25 poises at 25° C. (77° F.), corresponding to Tubes B to E if it is to be used with aluminum paste.

d. The flash point shall not be below 30° C. (86° F.) in a closed cup tester.

e. The varnish shall contain not less than 50% by weight of non-volatile oils and resin.

f. It shall pass a 140% Kauri Reduction Test, using the method described in Federal Specification TT-V-81, Paragraph F-2g.

g. It shall show no skinning after 48 hours in a three-quarters filled, tightly closed container.

h. It shall pass the gas and draft tests as described in U. S. Navy Specification 52V-14a.

i. Flow-out films on 28 gauge tin plate panels dried 72 hours shall withstand immersion in cold water for 96 hours and hot water (75° C. or 167° F.) for 6 hours without whitening, dulling, checking, or showing other serious defect.

j. Films applied to test tubes (dimensions 6"×1") by immersion in varnish to a depth of 4 inches and dried in an inverted position for 72 hours shall show no whitening, dulling, or visible attack when immersed to a depth of 2 inches in a 5% solution of sodium hydroxide for six hours (at 20° C. or 68° F.) and (a separate similar film) a 4% solution of acetic acid for 24 hours (at 20° C. or 68° F.).

k. A flow-out film on 28 gauge tin plate, air-dried 48 hours, shall be immersed in straight run gasoline 48 hours. After subse-

quent air drying for 2 hours the film shall show no whitening, dulling, or visible attack.

1. When thoroughly mixed with aluminum paste or powder in the proportion of 2 pounds per gallon of vehicle, the paint shall have good leafing quality, show satisfactory brushing and leveling properties and shall not break or sag when applied to a vertical, smooth, steel surface.

m. Aluminum paint made with this varnish, when applied to a metal panel and allowed to dry in a vertical position, shall set to touch in not less than 1 hour nor more than 3 hours and dry hard and tough in not more than 18 hours at a temperature of 20° C. (68° F.) to 30° C. (86° F.).

Vehicle—Glycerol Phthalate Resin Base Varnish.

This specification is designed to cover a glycerol phthalate resin varnish of maximum elasticity and durability for use in making aluminum paint for all exterior applications.

a. The varnish shall be of glycerol phthalate type containing not less than 35% glycerol phthalate (based on solids content) determined by the method described in Tentative U. S. Navy Specification ST-15b and shall be free from rosin or rosin derivatives as determined by the Liebermann-Storch Test.

b. It shall be clear and transparent.

c. The viscosity shall be between 0.50 and 1.0 poise at 25° C. (77° F.), corresponding to Tubes A to D of the Gardner-Holdt Air Bubble Viscometer, if it is to be used with aluminum powder, or between 0.65 and 1.25 poises at 25° C. (77° F.), corresponding to Tubes B to E if it is to be used with aluminum paste.

d. The flash point shall not be below 30° C. (86° F.) in a closed cup tester.

e. The varnish shall contain not less than 48% by weight of non-volatile matter.

f. The acid number of the vehicle shall be less than 8.

g. A flow-out film of the varnish on 28 gauge tin plate, air-dried 18 hours, and then baked at 82° C. (179.6° F.) to 85° C. (185° F.) for 2 hours, shall show no cracking of the film when suddenly chilled to 0° C. (32° F.) and quickly bent sharply on itself. The bent part of the baked panel shall show satisfactory adhesion under a knife test.

h. A flow-out film of the varnish on colorless glass air-dried 18 hours, then baked for not less than 2 hours, at 82° C. (179.6° F.) to 85° C. (185° F.) shall be hard, tough, smooth, transparent, and free from all defects such as checking, dulling, or wrinkling when compared to a fresh film.

i. It shall show no skinning after one week in a half-filled, tightly closed glass container stored in a dark place.

j. A flow-out film on 28 gauge tin plate, air-dried for 48 hours, shall withstand immersion in cold water for 18 hours without whitening and shall show only slight dulling. After removal from the water for 2 hours the original gloss and hardness shall return.

k. A flow-out film on 28 gauge tin plate, air-dried 48 hours, shall retain its gloss and general appearance after 24 hours' immersion in straight run gasoline. After air drying 4 hours, the film shall have regained its initial hardness and toughness. There shall be no dissolution effect on the lower immersed edge.

l. When thoroughly mixed with aluminum paste or powder in the proportion of 2 pounds per gallon of vehicle, the paint shall have good leafing quality, show satisfactory brushing and leveling properties and shall not break or sag, when applied to a vertical, smooth, steel surface.

m. Aluminum paint made with this varnish, when applied to a metal panel and allowed to dry in a vertical position, shall set to touch in not less than 1 hour nor more than 4 hours and dry hard and firm in not more than 16 hours at a temperature of 20° C. (68° F.) to 30° C. (86° F.).

Vehicle—Interior Varnish.

The vehicle for general use on steel or other metals, brick, concrete or plaster, subject to interior exposure, shall consist of a varnish fulfilling the following requirements:

- a. The varnish shall be clear and transparent.
- b. The viscosity shall be between 0.50 and 1.0 poise at 25° C. (77° F.), corresponding to Tubes A to D of the Gardner-Holdt Air Bubble Viscometer.
- c. It shall contain not less than 45% by weight of non-volatile oils and gums.
- d. It shall pass a 0% Kauri Reduction Test, using the method described in Federal Specification TT-V-71, Paragraph F-2f.
- e. When thoroughly mixed with aluminum paste or powder in the proportion of 2 pounds per gallon of vehicle, the paint shall have good leafing quality, show satisfactory brushing and leveling properties and shall not break or sag when applied to a vertical, smooth, steel surface.
- f. The *paint* shall set to touch in not more than 2 hours and dry hard and tough in not more than 18 hours at a temperature of 20° C. (68° F.) to 30° C. (86° F.).

Vehicle—Varnish Vehicle for Wood (Very Long Oil Varnish).

The vehicle for use on weather-exposed wood shall consist of a very long oil varnish, fulfilling the following requirements:

- a. The varnish shall be clear and transparent.

b. The viscosity shall be between 0.50 and 0.85 poise at 25° C. (77 F.), corresponding to Tubes A to C of the Gardner-Holdt Air Bubble Viscometer, if it is to be used with aluminum powder, or between 0.65 and 1.0 poise at 25° C. (77° F.), corresponding to Tubes B to D if it is to be used with aluminum paste.

c. It shall contain not less than 50% by weight of non-volatile oils and gums.

d. It shall pass a 100% Kauri Reduction Test, using the method described in Federal Specification TT-V-81, Paragraph F-2g.

e. When thoroughly mixed with aluminum paste or powder in the proportion of 2 pounds per gallon of vehicle, the paint shall have good leafing quality, show satisfactory brushing and leveling properties and shall not break or sag when applied to a vertical, smooth, wood surface.

f. The *paint* shall set to touch in not less than 3 hours nor more than 8 hours and dry hard in not more than 24 hours at a temperature of 20° C. (68° F.) to 30° C. (86° F.)

For Wood Not Exposed to Weather.

The vehicles for aluminum paint described as long oil varnish and interior varnish may be used.

Vehicle—For High Temperature Work.

Requirements for this type of vehicle shall be largely performance requirements, the composition being left entirely to the manufacturer, but fulfilling the following specification:

a. The vehicle shall contain not less than 20% non-volatile matter.

b. The viscosity shall be not greater than 0.50 poise, corresponding to Tube A of the Gardner-Holdt Air Bubble Viscometer.

c. When thoroughly mixed with aluminum paste or powder in the proportion of 2½ pounds per gallon of vehicle, the paint shall have good color and show satisfactory adherence to a smooth 26 gauge black iron panel and shall not crack nor peel when the panel is bent over a ¼-inch rod through an angle of 180°, after 10 hours heating of the panel at 500° C. (932 F.).

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